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Minister of Fisheries

The Effect of Flow Control on Freshwater Survival of Chum, Coho and Chinook Salmon in the Big Qualicum River

by

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Abstract

An environmental control project has been undertaken on a British Columbia coastal stream by the Department of Fisheries of Canada to increase the production of native chum, coho and chinook salmon populations. The works which have been constructed provide for stabilization of winter flows, increase in the minimum summer flow, and a degree of temperature control during summer and early fall. The freshwater survival rate of each species during a four-year period of natural flow conditions is compared with that resulting from the first two years of controlled flow. Chum salmon egg-to-fry survival ranged from 5 to 17 percent under natural conditions and was inversely related to the peak daily discharge during the incubation period. Survival rates in the two years of flow control were 25.2 percent and 24.5 percent respectively. The magnitude of the coho fry emigration near the river mouth was also related to winter discharge stability. Coho spawning populations of similar size, but affected by differing incubation conditions, produced fry emigrations amounting to 0.3 percent (natural flow) and 4.3 percent (controlled flow) of their respective egg potentials. Little variation occurred in coho smolt output over a five year period. Chinook salmon survival ranged from as low as 0.2 percent under natural conditions to 19.8 percent in one year of controlled flow. The largest production of chinook emigrants was accompanied by a substantial change in quality toward smaller size and earlier migration timing.

Introduction

The Big Qualicum River is being developed by the Department of Fisheries of Canada for the purpose of increasing the production of indigenous stocks of chum (*Oncorhynchus keta*), coho (*O. kisutch*) and chinook salmon (*O. tshawytscha*) through environmental control. The initial stage of the project, which is now completed, has included the construction of works to permit both complete regulation of the river discharge and a degree of water temperature control during the summer and early fall. The secondary stage, which has yet to be initiated, will consist of expansion and improvement of the existing spawning grounds.

Fluctuating discharge has been recognized as the major environmental factor involved in the large year to year variations in embryonic survival of Pacific salmon in coastal streams (Neave, 1953; Royce, 1954). It has been shown that egg-to-fry survival rates can be increased substantially by stabilization of river discharge (Wickett, 1952; Gangmark and Bakkala, 1960) and it has also been indicated that the increased survival can be carried through to the adult stage (MacKinnon, Edgeworth and McLaren, 1961). This knowledge provided the biological basis for the Big Qualicum

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project. Under the controlled flow regime now in effect on the Big Qualicum River winter flows have been stabilized and the minimum summer discharge level has been raised. In addition to providing stable spawning area for all species the controlled flow regime is expected to increase the stream rearing capacity for coho salmon.

Feasibility studies were initiated in 1957. It was evident during these studies that extreme flooding had, in some years, caused extensive loss of chum salmon spawn and reduced the amount of suitable spawning area through scouring (Wickett, 1959). Construction of the flow control stage of the project commenced in 1960 and was completed in 1964. By November, 1963 flow control had begun and during the following two winters discharge was maintained within a much more stable range than would have occurred under natural conditions.

A study to determine the effects of flow control on the freshwater production of salmon in the Big Qualicum River was started in September, 1959, to provide four years of information on survival rates prior to control. This paper describes the survival rates of chum, coho and chinook salmon relative to stream discharges during the pre-control period and compares them with the results obtained in the first two years of controlled flow. A brief description of the stream and the project is also presented. The project and the basis for its implementation have been described in detail by Clay and Fahlman (1962).

General Description

The Big Qualicum River is located on the east coast of Vancouver Island, British Columbia, approximately 39 miles north of the city of Nanaimo (Figure 1). The headwaters of the system, situated at elevations of up to 4000 feet above sea level, drain through steep glacially-eroded valleys into Horne Lake, which is three square miles in area and 180 feet at maximum depth. In the first one-half mile downstream of the lake the river drops 190 feet through a series of four falls. Between the base of the falls and the river mouth at the Strait of Georgia there is approximately 6.5 miles of river accessible to salmon. Hunt's Creek, the only major tributary between the lake and the sea, enters four miles downstream of the lake.

The drainage area of the Big Qualicum River totals 58 square miles, of which 42.5 square miles are tributary to Horne Lake. On the basis of 13 years of record the mean annual discharge at the river mouth is 286 cubic feet per second. The maximum and minimum discharges recorded have been 7080 cfs and 14 cfs respectively. Approximately 85 per cent of the system's annual runoff comes from Horne Lake, but the portion of the daily runoff contributed below the lake is highly variable, due mainly to flash freshets from Hunt's Creek. The mean annual discharge of Hunt's Creek is in the order of 20 cfs and its maximum discharge approximates 2500 cfs.

The average rate of fall of the Big Qualicum River between the lower falls and the sea is six feet per thousand feet. The total stream bed area is 275,000 square yeards and the average width is approximately 70 feet. Wetted area at discharges of 33 cfs and 230 cfs is 186,000 square yards and 260,000 square yards. The riffle portion of

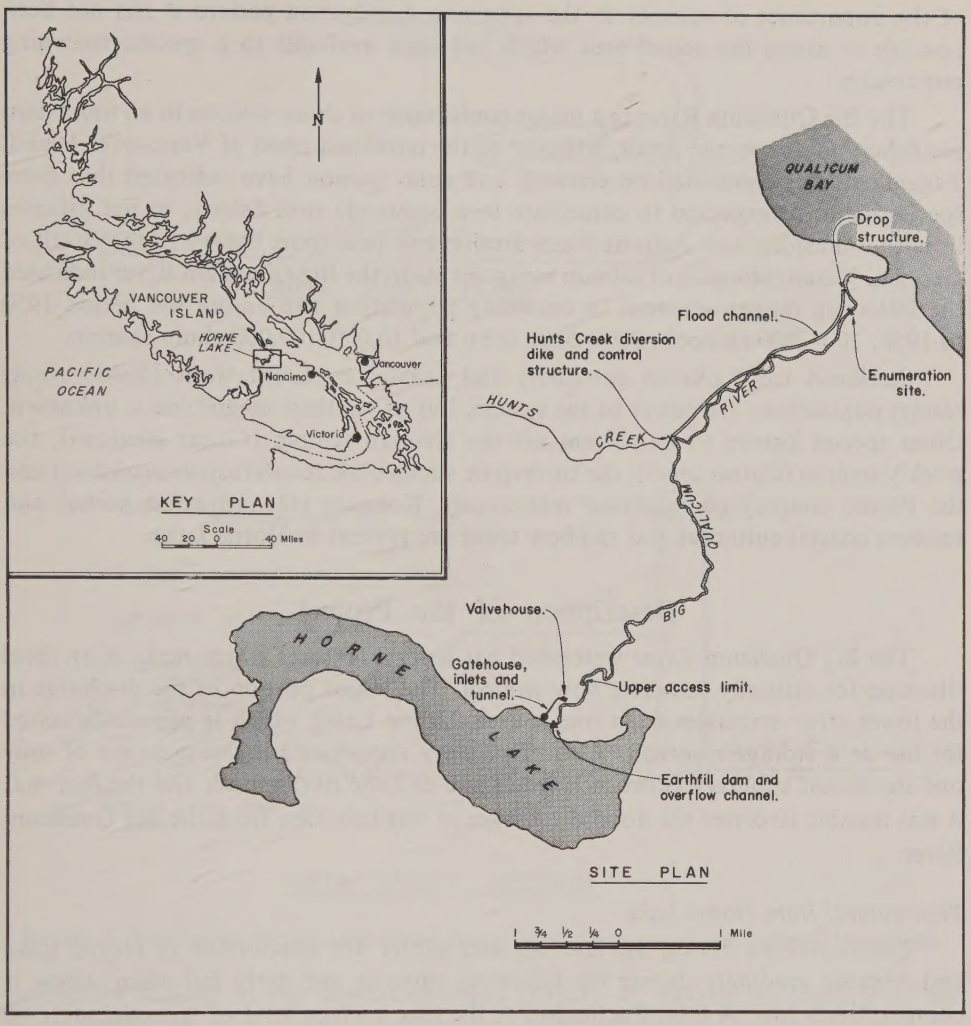

FIGURE 1. *Map showing the location of the watershed in southwestern British Columbia and important features of the project.*

total stream area increases from an estimated 33 percent at 33 cfs to 63 percent at 230 cfs, while over the same discharge range, the pool portion decreases from 59 percent to 14 percent.

Reasonably precise estimates of the spawning area available have been difficult to obtain under natural flow conditions. Observations of chum salmon spawner distribution indicate that approximately 20 percent of the stream area is utilized at discharges of 200–250 cfs, and some additional area becomes available at higher and lower discharges as a result of changes in velocity and depth. Discharges in excess of 250 cfs increase wetted area only slightly but accompanying velocity increases are sufficient to restrict chum salmon spawning to marginal areas. Under natural conditions discharge during spawning can be highly variable and because

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of the importance of velocity to the spawning distribution pattern it has not been possible to assess the actual area which has been available to a specific spawning population.

The Big Qualicum River is a major contributor of chum salmon to an important net fishery in Johnstone Strait, adjacent to the northeast coast of Vancouver Island. Tagging studies conducted on chinook and coho salmon have indicated that these species could be expected to contribute to a coastwide troll fishery, to net fisheries in both Johnstone and Juan de Fuca Straits, and to a sport fishery in the Strait of Georgia. Visual estimates of salmon escapements to the Big Qualicum River indicated the following ranges occurred in spawning population size during the period 1950 to 1958: 200–2000 chinook, 2000–5000 coho and 10,000–100,000 chum salmon.

Steelhead trout (*Salmo gairdneri*) and coastal cutthroat trout (*Salmo clarki clarki*) populations are native to the system, but as yet their magnitude is unknown. Other species known to be present are the aleutian sculpin (*Cottus aleuticus*), the prickly sculpin (*Cottus asper*), the threespine stickleback (*Gasterosteus aculeatus*) and the Pacific lamprey (*Entosphenus tridentatus*). Kokanee (*Oncorhynchus nerka*) and resident coastal cutthroat and rainbow trout are present in Horne Lake.

Description of the Project

The Big Qualicum River watershed has several features which make it an ideal situation for virtually complete flow control. The major portion of the discharge in the lower river originates from one source, Horne Lake, which is physically suited for use as a storage reservoir. Also of primary importance is the presence of only one significant tributary between Horne Lake and the river mouth and the fact that it was feasible to divert the flood discharges of this tributary from the Big Qualicum River.

Flow control from Horne Lake

Excess inflows during the late fall and winter are impounded in Horne Lake and released gradually during the following summer and early fall when inflow is comparatively low. A total fluctuation in the lake surface level of approximtely 80 feet is necessary to achieve the required storage capacity (142,000 acre-feet). A drawdown of up to sixty feet below the natural surface elevation is accomplished by means of a vertical concrete gate shaft, 98 feet deep, which has three separate gate-controlled intakes with bottom elevations at 17.5 feet, 38 feet and 82 feet below the natural lake surface (Figures 2 and 3). Flood control storage above the former lake level is provided by a dam in the natural lake outlet. Although the lake surface can be lowered to elevation 335 during periods of extreme drought, the normal operating range will be between elevations 355 and 385.

Through the use of the three intake levels it is possible to take advantage of thermal stratification in the lake during the summer and fall and thereby provide a degree of temperature control in the river by mixing water drawn from different depths. Water drawn into the gate shaft passes through a tunnel, approximately 1700 feet long, before being discharged into the natural river bed below the base of the second falls. The rate of discharge from the tunnel is controlled precisely by means of

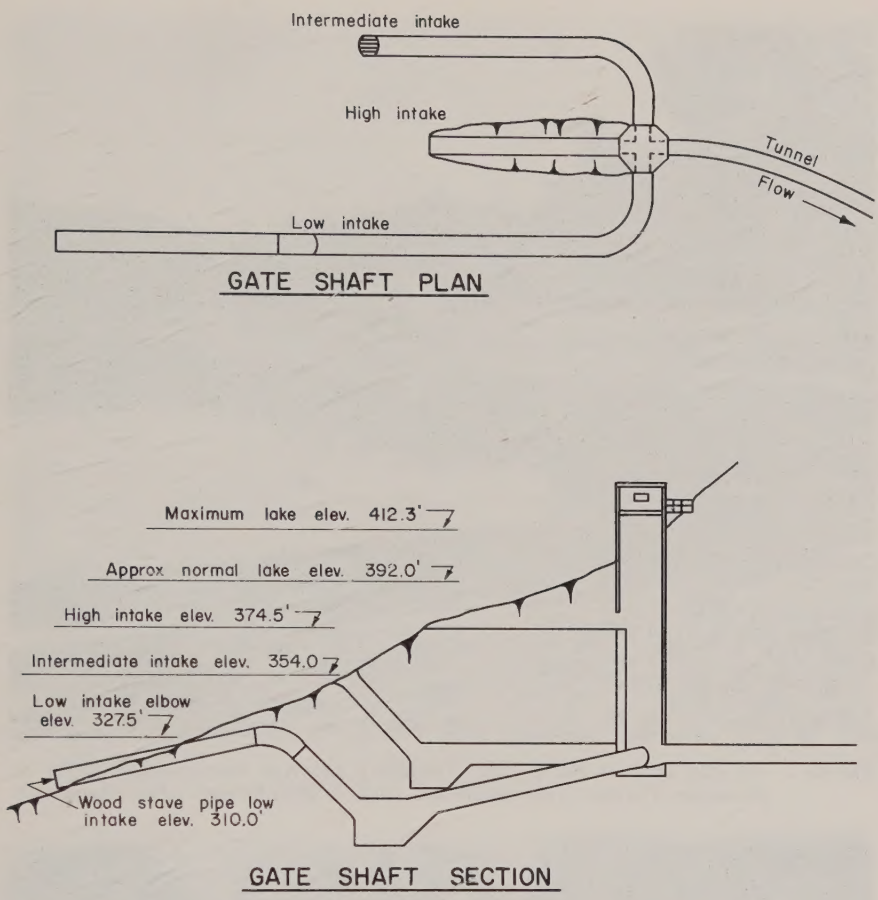

FIGURE 2. *Diagram of the gate shaft intake system located near the natural outlet of Horne Lake.*

two valves located at the downstream end (Figure 4). Maximum capacity of the valves is 1000 cfs.

The schedule of flow releases to the river and the relation to the various life stages of each species is shown in Figure 5. The discharge range maintained during any one period in a given year will be much narrower than the overall ranges shown in the figure. The controlled range of discharge can be compared with that occurring under natural conditions by reference to Table 1 in the Appendix.

Hunt's Creek Diversion

Freshets from Hunt's Creek, which could cause damage to spawning area in the lower Big Qualicum River, are isolated from the regulated flows by means of a diversion dam and an open-cut flood channel (Figures 6 and 7). The flood channel follows the north side of the valley for 2.5 miles before joining the river immediately above tidewater. Adult salmon are excluded from the flood channel by a drop structure at its downstream end. A discharge of up to 50 cfs, passed through a culvert in the diversion dam, provides natural access to upper Hunt's Creek for coho salmon and steelhead trout.

FIGURE 3. *The gate shaft on Horne Lake. The lake is shown at approximately 30 feet of drawdown. The dam in the natural lake outlet is in the far right of the photograph.*

FIGURE 4. *The valvehouse and former river channel at the second falls below Horne Lake.*

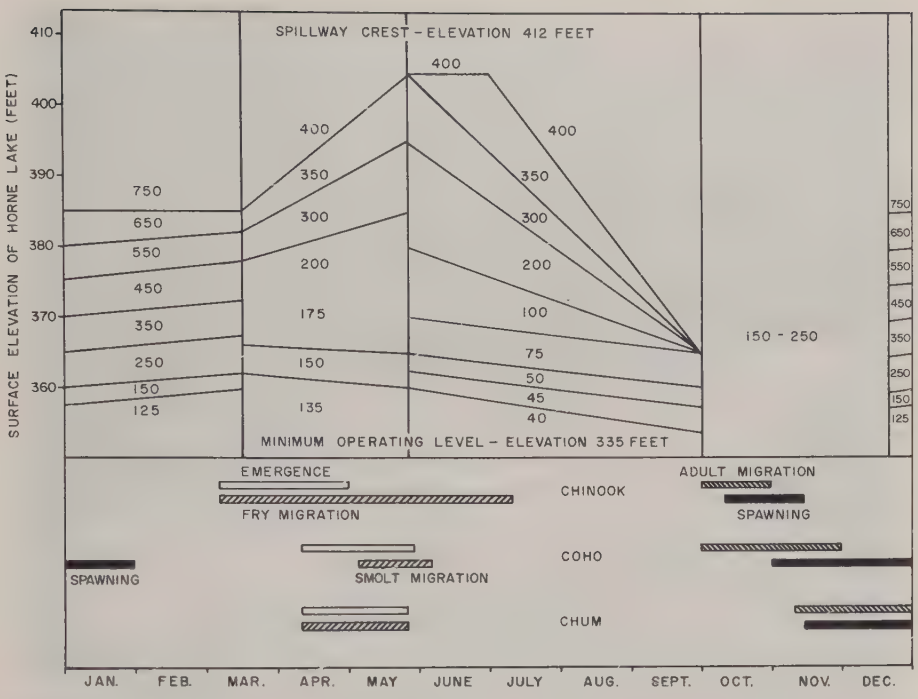

FIGURE 5. *Controlled flow schedule of the Big Qualicum River and its relation to the life stages of each species of salmon. The discharge (cfs) released from the valves is dependent within each period on the surface elevation of Horne Lake.*

FIGURE 6. *The Hunt's Creek flood channel and dike following the north side of the valley.*

FIGURE 7. *Diversion dam at the upstream end of the flood channel. The dam and an intake works for passing flow into the original channel of Hunt's Creek are shown in the left of the photograph.*

Methods

Since 1959 adult salmon have been enumerated at a fence located 2300 feet upstream of mean tidal influence (Figures 1 and 8). Although operational problems have been encountered for short periods in some years it has generally been possible to obtain complete counts. The fence was inoperative during the chum salmon migration twice in 1959 and once in 1960. In each of these cases the rate of migration reached a peak during rising discharge, and by the time the fence was removed it had declined to a low level. For this reason chum salmon counts in those years are regarded as reasonably accurate. High discharge over an extended period in 1963 made it impractical to obtain a complete count of the coho escapement.

In order to estimate the egg depositions of chinook and chum salmon, measurements have been obtained of sex and length composition and the degree of egg retention. Length-fecundity relationships have been used with the size data to estimate the mean fecundity. Summaries of the data used are given in Tables 2 and 3 of the Appendix. Chum salmon measurements were obtained both from carcasses recovered on the spawning grounds and from those which drifted against the fence. In determining the overall sex composition the male-to-female ratio at the fence has been used to correct for any excessive drift of males from upstream recovery areas. In three of the five years for which data are given measures of chinook sex and

size composition were obtained from fish trapped at the fence rather than from dead recovered on the spawning grounds. Because an insufficient number of fecundity measures were obtained from Big Qualicum chinook salmon it has been necessary to use fecundity data which has been collected in studies of fall chinook in the Stamp River, located on the west coast of Vancouver Island.

Downstream migrants have been trapped on a 24-hour basis from early March to mid-July in an operation which, with the exception of 1960, has been essentially the same in all years. The traps consist of expanded metal-type screen troughs one foot wide by twelve feet long, with attached liveboxes (Figure 9.) They are spaced at approximately eight-foot intervals across the stream and allow sampling of vertical sections from the water surface to the stream bed comprising 13.5 percent of the stream width.

Juvenile salmon population estimates are based on mark and recapture tests which have involved the release of marked migrants 100–200 yards upstream from the fence. Chum salmon fry have been marked by immersion in Neutral Red dye and temporary fin marks have been used on coho salmon smolts and large late-migrating chinook salmon fry. A summary of the results is given in Appendix Table 4. The estimated yearly percentages of the chum salmon fry emigration taken by the gear have also been applied for estimating the numbers of newly-emerged coho and chinook fry emigrants. The relatively low percentage recapture of coho smolts and

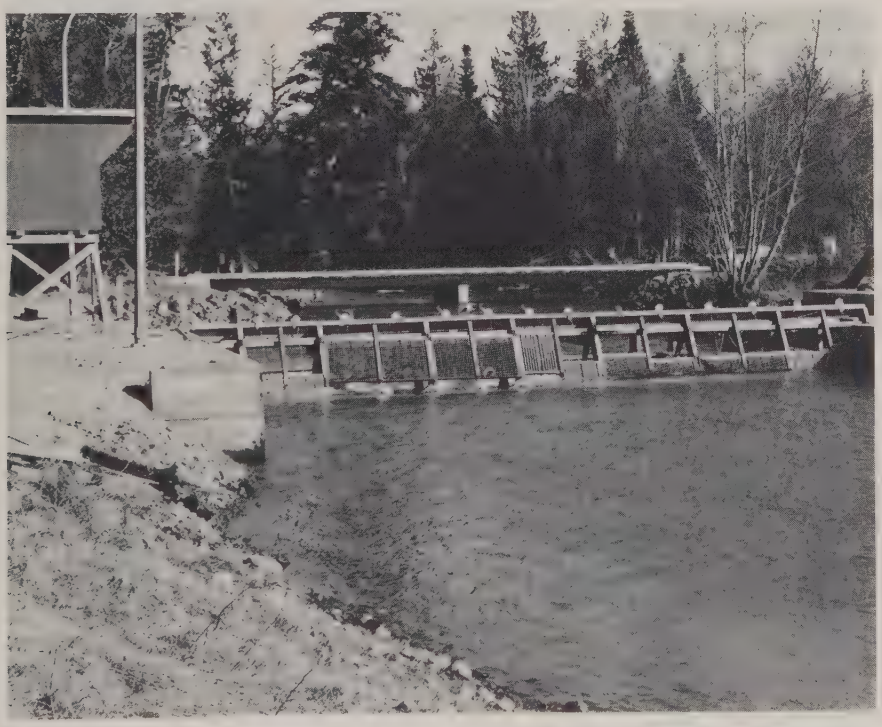

FIGURE 8. *View of the counting fence from upstream during adult enumeration. Salmon are counted as they pass over a white background by an observer stationed in the tower on the left bank.*

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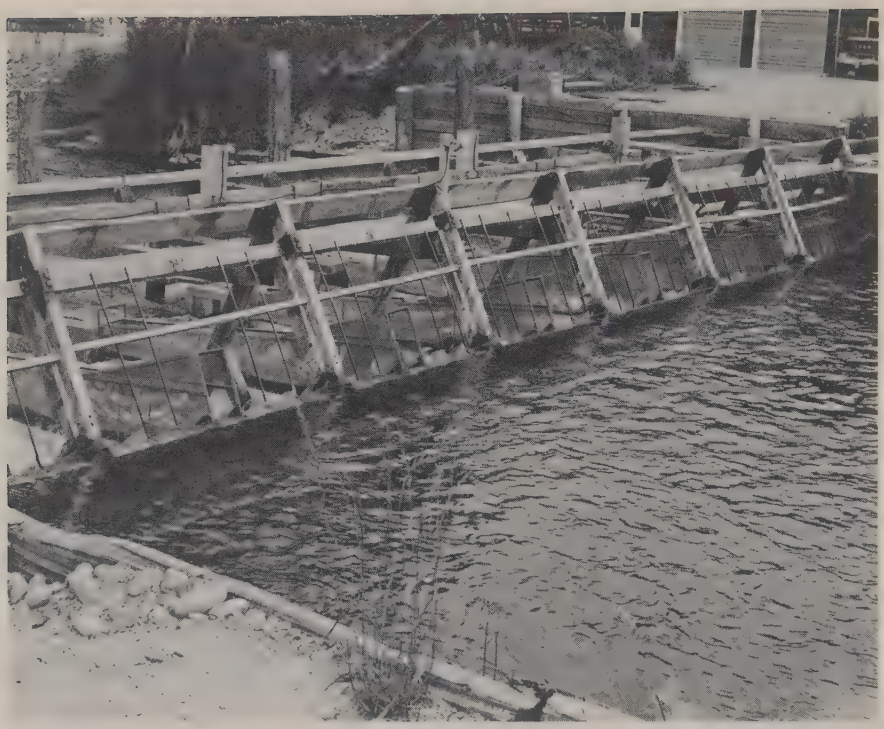

FIGURE 9. *Fence site during downstream migrant enumeration. The river flow passes over a board, anchored to the stream bottom, and drops approximately one foot into the traps.*

late-migrating chinook fry (Appendix Table 4) as compared to the portion of the stream width sampled probably indicates considerable avoidance of the trapping gear.

There were no mark and recapture tests conducted with the 1960 and 1961 brood late-migrating chinook fry. The general range of magnitude of these populations has been estimated by using the total range of gear efficiency which may have applied. The lower limit of each range was determined by the gear efficiency estimate for chum salmon fry, while the upper limit was based on the assumption that the degree to which late-migrating chinook fry avoided the gear was of the same magnitude as that measured with coho smolts in 1961.

The daily discharge and temperature of the Big Qualicum River has been recorded throughout the study period by means of continuous temperature recorders near the river mouth and at the Horne Lake outlet and a staff-gauge hydrometric station near the river mouth. The mean and extreme discharges in each month of the study are shown in Appendix Table 1.

Results and Discussion

1. Chum Salmon

The freshwater survival rate of chum salmon over a four-year period of natural conditions averaged 11.2 percent. By comparison, survival rates of approximately

25 percent were achieved in the two years of flow control (Table I). Survival rates calculated from the apparent actual egg deposition (i.e. potential egg deposition minus egg retention) to eliminate mortality occurring prior to deposition are compared in Table II to the discharge extremes in each incubation period. An inverse relation between survival rate and the magnitude of the peak discharge is clearly demonstrated in Figure 10, but no relation between survival rate and the minimum discharge is apparent. It is possible that the effects of low discharges were masked by those of extreme freshets.

Table I.

Chum Salmon Fence Counts, Egg Retention and Total Freshwater Survival, Big Qualicum River, 1959–64.

Brood Year	Adult Count	Percent Egg Retention	Potential Egg Deposition (Millions)	Fry Output (Millions)	Percent Survival
1959	83,500	24.5	128.9	17.7	13.7
1960	47,491	5.0	73.7	3.7	5.0
1961	10,421	4.4	20.1	3.4	17.0
1962	34,465	5.5	54.3	4.9	9.1
1963	27,897	2.7	52.4	13.2	25.2
1964	24,410	2.8	39.8	9.8	24.5

Egg retention constituted a major loss only in 1959, the year of the largest spawning population. Under conditions of artificial manipulation an increase in spawning density has been demonstrated to raise the level of egg retention (Hanavan and Skud, 1954; Semko, 1954; Mathisen, 1962). However, under natural stream conditions significant egg retention levels are not normal even when seasonal spawning densities of pink and chum salmon are relatively high (Hunter, 1959; McNeil, 1964). The extent of competition appears to be related to instantaneous density, or the distribution of spawning effort in space and time, rather than the overall seasonal spawning density.

Table II.

Chum Salmon Survival from Actual Egg Deposition to Fry Migration in Relation to Discharge Extremes during Incubation, Big Qualicum River, 1959–64.

Brood Year	Percent Survival	Discharge Range (cfs)	
		Daily Maximum	Daily Minimum
1959	18.2	1360	99
1960	5.3	3200	156
1961	17.8	1260	108
1962	9.6	2000	59
1963	25.9	800	280
1964	25.2	393	150

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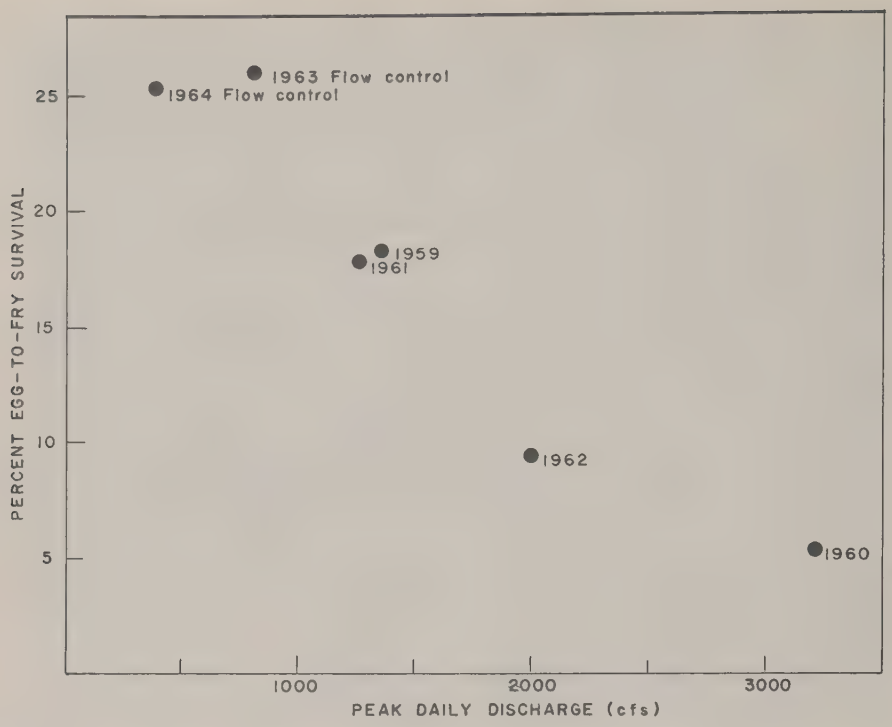

FIGURE 10. *Chum salmon egg-to-fry survival in relation to peak discharge during the incubation period. Survival rates are calculated from potential egg deposition corrected for egg retention.*

Tagging studies have shown that Big Qualicum chum salmon characteristically delay at the mouth of the river and enter as mature fish within three to four days of spawning. In 1959 migration into the river was unusually constricted, in that 38,000 fish or 46 percent of the season total moved through the fence on two days, November 19 and 20. This migration occurred on rapidly rising discharge after a period of extremely low discharge. Comparison of the upstream distribution of spawners in 1959 with that of the relatively small population in 1961 (Figure 11) shows that the large population spread no more extensively over the available area. There was no indication of a response to population pressure, as would be expected from observations elsewhere (Hunter, 1959; Merrell, 1962). The constricted migration pattern and lack of upstream distribution in 1959 may reflect excessive delay of mature chum salmon at the river mouth. Also, during the peak of spawning in late November discharges of 500 to 800 cfs prevailed, confining much of the spawning to the stream margins and thereby reducing the amount of available spawning area. It is likely that two environmental factors, low discharge prior to stream entry and high discharge during peak spawning, in the presence of a large population combined to promote excessive competition for spawning area.

Over the range in adult population size observed to date flow stability appears to have been the major factor inducing variability in the freshwater survival rate of chum salmon. With the exception of the high egg retention recorded in 1959 there

has been no evidence of mortality which is either positively or negatively related to adult population size through such factors as superimposition, operating in a density-dependent manner (McNeil, 1964), or predation on emergent fry, which Hunter (1959) has demonstrated to be inversely density-dependent in a coastal stream situation. This observation is supported by the peak discharge-survival relationship and the fact that comparable high survival rates have been recorded with both the largest and smallest spawning populations.

2. Coho Salmon

Fry Emigration

During the April-May emergence period and to a lesser extent in June, newly-emerged fry migrate seaward past the fence site. Comparable migrations of coho fry have been reported in several other coastal streams (Chapman, 1962). In five years of study the magnitude of this emigration, shown in Table III, has closely reflected the stability of winter flows. Relatively large emigrations have resulted from the two broods subjected to flow control (1963 and 1964), whereas the two smallest emigrations resulted from broods encountering the highest peak discharges during incubation (1960 and 1962). Adult populations of similar size, but affected by differing incubation conditions, have produced greatly different numbers of emigrants. The numbers of emigrants produced by the 1962 and 1964 broods amounted to 0.3 percent and 4.3 percent respectively, of potential egg deposition.

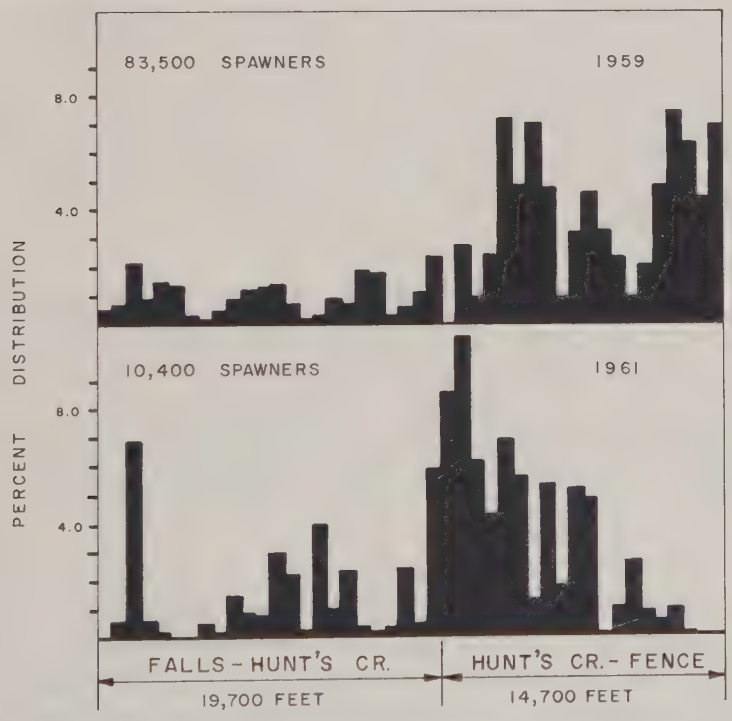

Figure 11. *Live count distribution of chum salmon at peak of spawning, 1959 and 1961. Counts were made by stream sections approximately 800 feet long from the upper limit of access to the counting fence near the river mouth.*

Table III.

Coho Salmon Fry Emigration and corresponding Adult Population Size, Big Qualicum River Fence, 1960–64.

Brood Year	Adult Count[1]	Fry Emigration
1960	2562	17,200
1961	2886	63,800
1962	4618	32,100
1963	1291[2]	420,700
1964	5130	535,900

[1]Includes jack coho counts, which in 1961, 1962 and 1964 were 600, 395, and 369 respectively.
[2]Incomplete count.

Chapman (1962) concluded that aggressive behaviour is one factor causing the downstream migration of coho fry and that this aggression and consequent emigration are probably density-regulating mechanisms. He found that downstream migrant fry would cease their migration if introduced to stream areas barren of resident fry. It seems reasonable to conclude that the egg-to-fry survival rate of coho in the Big Qualicum River has been increased by controlled winter flow and that this has produced larger emergent fry populations than those of the preceding three years. It is likely that the increase in emigration is much more than proportionate to the increase in embryonic survival. In the last two years emigrant fry would appear to have comprised a much larger percentage of the emergent population than in the three years prior to flow control. The evidence is strong that the magnitude of emigration has depended to a large extent on the density of emergent fry. Considering Chapman's findings, it is concluded that fry populations in the two years of controlled flow greatly exceeded the initial rearing capacity of the stream.

Smolt Emigration

The majority of juvenile coho salmon reside one year in the Big Qualicum River and Hunt's Creek before migrating to sea, but a small percentage of individuals remain for two years. Analysis of scale samples collected over a five-year period from a total of 371 smolts revealed that 97.3 percent were Age I.

Estimates of coho smolt output have been examined for a relationship with the stream flows recorded in the summer previous to emigration (Table IV). The data includes three years of natural flow conditions, one year in which conditions were altered by construction activities (1961 brood), and one year of flow control (1963 brood). The range in smolt output has been small in the five years of record, suggesting that fluctuations in fry abundance have had little or no effect on smolt abundance.

Several studies have given indirect evidence that coho smolt output is related to the minimum summer discharge level. Neave (1949) demonstrated a positive relationship between the minimum summer discharge in the Cowichan River, Vancouver Island, and the availability of adult coho to the local sport fishery two years later. Over a four-year period at Nile Creek, Vancouver Island, smolt output was found to be positively related to the minimum monthly rainfall during the summer of stream

Table IV.

Coho Salmon Smolt Output in Relation to Low Summer Discharge, Big Qualicum River, 1959–63.

Brood Year	Adult Count	Estimated Smolt Output	August-September Discharge Near River Mouth (cfs)	
			Mean	Daily Minimum
1959	3624	30,600	31.1	25
1960	2562	26,000	22.1	14
1961	2886	34,300 (28,100)[2]	186[1]	32
1962	4618	33,400 (27,900)[2]	28.9	25
1963	1291[3]	34,700 (30,300)[2]	47.6	32

[1]Relatively high fluctuating flows due to construction activities.

[2]Figures in brackets are estimates of the Big Qualicum output, excluding Hunt's Creek contribution.

[3]Incomplete count.

residence (Wickett, 1951). McKernan et al (1950) showed fluctuations in gillnet catches of adult coho in the Siletz River, Oregon to be significantly correlated with the summer flow level which had occurred two years previously but the same correlation for the Coquille River in Oregon was insignificant. Although the lowest smolt output from the Big Qualicum River was associated with the lowest minimum summer discharge (1960 brood), there has not been a sufficient range of conditions to establish whether any clear relationship exists between discharge and smolt output. Controlled conditions will provide further opportunity to assess this relationship, as minimum discharges will generally exceed by several times those observed to date.

The 1961 and 1962 brood smolt outputs from the Big Qualicum River, exclusive of Hunt's Creek, were approximately 16 per 100 square yards of wetted stream bed at the minimum discharge. This is low in comparison to that reported by Chapman (1964) for three relatively small Oregon streams in which the output over a four-year period averaged approximately 37 smolts per 100 square yards. Smolt biomass produced per unit area in these streams was approximately twice that of the Big Qualicum River.

3. Chinook Salmon

Most chinook salmon spawn in the upper two miles of the Big Qualicum River. Hunt's Creek is not utilized for either spawning or rearing. Chinook fry emergence takes place during March and April and emigration is complete by mid-July of the same year. The downstream migration pattern at the fence tends to be bimodal (Figure 12). The position of the modes indicates that fry emigrate either within a short time of their emergence or after six weeks or more of rearing. The size distribution of fry caught at the fence also reflects these two main groups, in that the

majority of individuals measure either between 40 mm and 48 mm fork length (measured live, anaesthetized) or 60 mm and 90 mm. The mean length of late-migrating fry at any given time generally falls between 70 mm and 80 mm. Separation of emigrants into early and late groups, as in Figure 12, is based on samples taken for length measurements at least once weekly over the entire migration period. The size division point is a length of 55 mm.

Table V.

Chinook Salmon Fry Output and Freshwater Survival, Big Qualicum River, 1960–64.

Brood Year	Adult Count	Potential Egg Deposition (Millions)	Estimated Fry Emigration		Percent Survival
			Early	Late	
1960	1511	3.54	3,000	3,100—5,600[1]	0.17—0.24
1961	1087	1.49	29,000	45,800—75,500[1]	5.0 —7.0
1962	787	1.95	41,700	39,400	4.2
1963	619	1.41	241,000	37,000	19.8
1964	697	0.87	35,100	69,400	12.0

[1]Range estimate given because actual gear efficiency for late chinook fry was not tested (See Methods)

Freshwater survival rates and the estimated numbers in each group of emigrants are shown in Table V for three years of natural flow conditions and for the two years of flow control. Because a large portion of the fry population tends to reside in the stream for varying periods and is therefore subjected to a degree of natural mortality prior to emigration the survival rates given are lower than the survival to emergence. The 1963 brood would most closely reflect emergent survival because of the predominance of newly-emerged fry in the emigration. This was also the only year in which the number of migrants in the early group could have equalled or exceeded the number remaining in the stream.

The high mortality recorded for the 1960 brood is thought to have resulted from extreme flooding in January, 1961, which also severely affected chum salmon. The survival rate in that year was probably in the order of one percent or less. The low output of both groups of chinook fry from the 1960 brood may indicate not only a small emerging fry population but also a lack of sufficient fry to fully utilize available rearing area. Inadequate fry emergence was not apparent in 1960 brood coho salmon. However, coho spawning is more widely distributed in the watershed and its duration is much greater than that of chinook (i.e. three months as compared to one month). Both of these characteristics tend to ensure adequate numbers of emerging fry under extreme environmental conditions.

Measures of the total freshwater mortality of chinook salmon comparable to those made at Big Qualicum have not, to our knowledge, been reported in the literature. Gangmark and Bakkala (1960), compared survival rates of artificially-planted

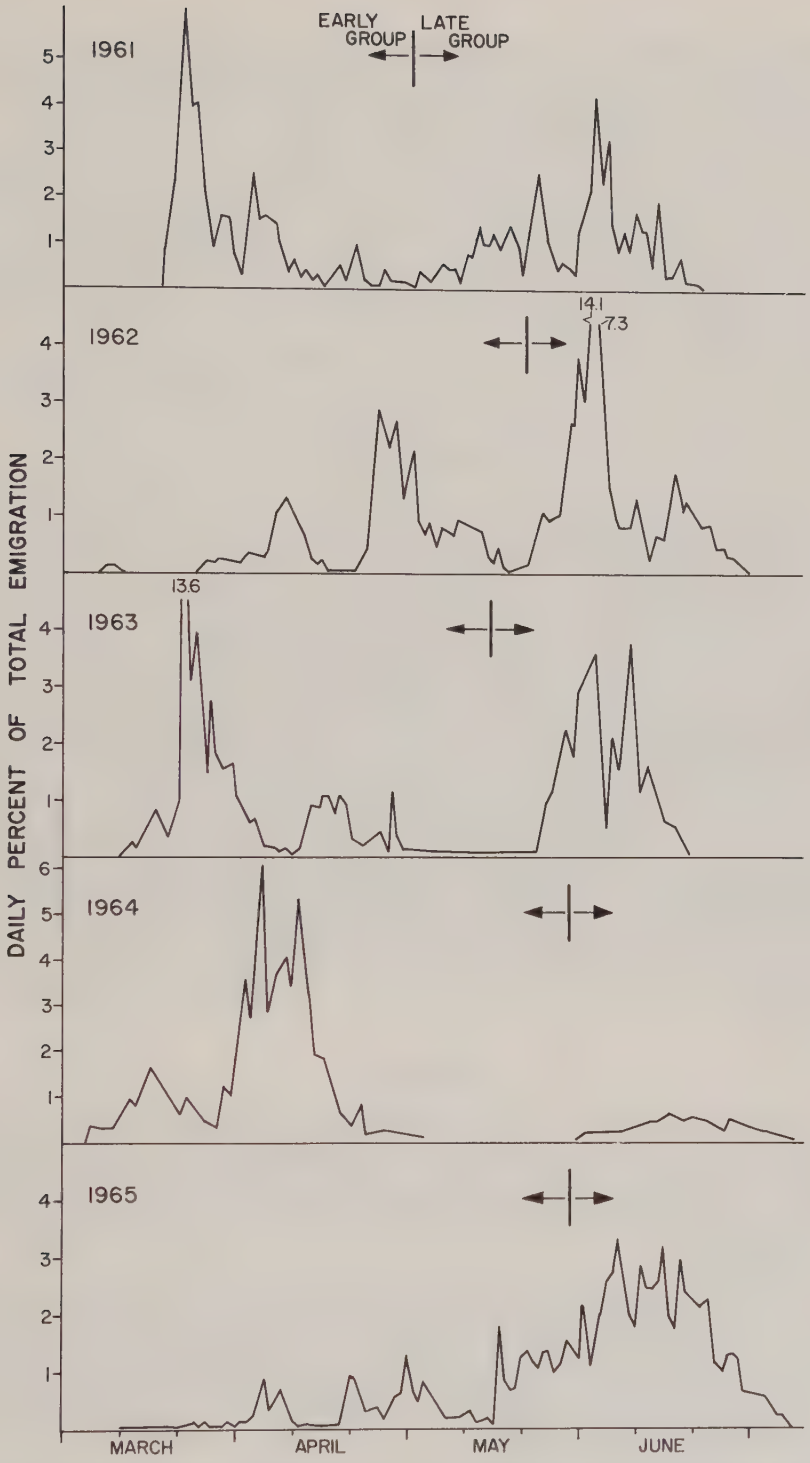

FIGURE 12. *Downstream migration timing of chinook salmon fry at the fence site, showing dates of separation into early and late groups.*

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chinook eggs in stable and unstable stream channels. Survival rate to the advanced alevin stage in a controlled flow situation approximated 60 percent, whereas in the natural stream bed extreme flooding resulted in survival rates as low as 1.7 per cent and zero. At Fall Creek, a tributary of the Sacramento River, the chinook survival rate from deposited egg to fry migrant ranged from 7 to 32 percent over a four-year period, the highest survival occurring in a year of particularly stable flow (Wales and Coots, 1954). As the fry trapping site employed in that study was located within one mile of all spawning and since the majority of migrants were reported to have recently emerged, these survival rates were probably close to the actual rates from egg deposition to fry emergence.

The restricted range over the last four years in late-migrating fry output from the Big Qualicum suggests that there is some consistency in the stream's capacity to rear juvenile chinook to that stage. A large emigration of newly-emerged fry, such as that occurring in the first year of flow control (1963), may reflect an emerging fry population which greatly exceeded the initial rearing capacity of the stream. With a larger adult escapement than those of the last two years and stable winter flows the fry emergence is likely to increase substantially. If the magnitude of the early group is mainly density-dependent, an increase in the emergent fry population would result in a significantly larger early emigration than any observed to date. This would change the overall quality of the fry output toward smaller size and earlier migration timing. There is evidence that the change would result in a lower rate of ocean survival and that early group fry may contribute very little to adult production. A study of the comparative fry-to-adult survival in two groups of marked fall chinook, roughly equivalent in size to the early and late migrating Big Qualicum fry, was undertaken at the Spring Creek hatchery on the Columbia River (Junge and Phinney, 1963). Fry reared for three months prior to release from the hatchery survived at 18 times the rate of fry released unfed. Multiple correlation analysis, relating adult return to Spring Creek over nine broods to the magnitude of the fry and fingerling releases involved, also indicated that variation in returns was completely dependent on the magnitude of fingerling releases and was not influenced by the quantity of fry released.

Summary

1. As part of a continuing program to assess the effect of controlled flow on the chum, coho and chinook salmon production of the Big Qualicum River freshwater survival rates were measured and related to stream flow over a six-year period from 1959 to 1964. The first four years of the study were conducted under natural flow conditions.
2. At the adult population levels encountered, chum salmon egg-to-fry survival rates were inversely related to the maximum daily discharge during each incubation period. The freshwater survival rates in the first two years of controlled flow were 24.5 and 25.2 per cent, as compared to an 11.2 per cent average recorded under natural conditions.
3. The abundance of emerging coho fry, as indicated by the size of the emigration at the fence site, was dependent upon the stability of the winter discharge. The

total emigration increased from a maximum of 64,000 fry under natural flow conditions to 421,000 and 536,000, respectively, in the two years of flow control.

4. Coho salmon smolt output ranged from 26,000 to 35,000 over a five-year period. No clear relationship between output and the minimum summer discharge is evident. However, the range in discharge levels was small.

5. The freshwater survival rates of chinook salmon under natural conditions did not exceed 7 per cent, and in the year of most extreme flooding (1960) approximated only 0.2 per cent. Under controlled flow survival rates increased to 19.8 per cent and 12 per cent, but the highest survival rate was accompanied by a substantial change in the quality of the fry output toward smaller size and earlier migration timing.

Acknowledgments

The Big Qualicum River Project was conceived by and initiated under the direction of C. H. Clay, Chief of Resource Development Branch, Pacific Region, Department of Fisheries of Canada, and R. E. McLaren, Chief Biologist.

Engineers who have been closely associated with construction of the project and have aided in providing facilities for the assessment programs have been: R. A. Fahlman, senior construction engineer, B. A. Heskin, B. W. Howard, J. P. Parkinson and J. A. Wood. Dr. P. A. Larkin, director, Fisheries Research Board of Canada Biological Station, Nanaimo, B.C., and M. C. Bell, of the University of Washington, provided valuable advice during the planning of the project. I. S. Todd was the project biologist in charge of the assessment study during 1961. The authors are grateful to F. C. Boyd for the use of the chinook salmon fecundity data.

R. A. L. Harvey, senior technician, has worked on the project almost continuously since 1959. His enthusiasm and resourcefulness have been valuable attributes in the collection, tabulation and analysis of biological data.

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Appendix

Table 1.

Mean and extreme monthly discharges near the mouth of the Big Qualicum River, September, 1959 to June, 1965[a].

		1959	*1960*	*1961*	*1962*	*1963*	*1964*	*1965*
January	Max.		1300	3200	1260	1020	800	228
	Mean		258	1040	504	320	710	171
	Min.		99	198	179	70	580	150
February	Max.		1020	1130	260	2000	585	393
	Mean		564	868	203	672	567[b]	295
	Min.		181	473	120	59	535	181
March	Max.		538	970	252	580	535	393
	Mean		220	472	154	250	330[b]	265
	Min.		133	272	108	69	310	178
April	Max.		680	379	320	344	310	187
	Mean		437	220	197	255	293[b]	177
	Min.		318	156	140	152	280	168
May	Max.		306	250	404	229	388	181
	Mean		246	208	196	148	310	173
	Min.		184	152	108	78	280	130
June	Max.		232	154	145	75	278	117
	Mean		154	117	102	53	173	83
	Min.		96	68	57	37	150	77
July	Max.		94	67	63	47	165	
	Mean		61	44	47	42	141	
	Min.		38	28	34	36	70	
August	Max.		37	27	901	40	75	
	Mean		29	20	208	31	49	
	Min.		25	14	33	26	32	
September	Max.	52	37	39	905	28	99	
	Mean	41	34	25	169	26	46	
	Min.	36	31	16	32	25	32	
October	Max.	130	409	234	327	1480	274	
	Mean	71	138	117	160	445	234	
	Min.	43	28	38	36	32	106	
November	Max.	836	818	422	549	935	291	
	Mean	277	426	263	270	716	269	
	Min.	100	160	160	132	650	231	
December	Max.	1360	834	680	1340	765	281	
	Mean	588	476	362	624	594	234	
	Min.	228	213	186	248	485	168	

[a]Published and unpublished data from the Dept. Northern Affairs and National Resources, Water Resources Branch. Surface water supply of Canada, Pacific Drainage. Water Resources Paper Nos. 128, 131, 136 and 139. Data shown after September, 1962 are unpublished and subject to revision.

[b]Discharge as released from the valves; up to 100 cfs higher near the river mouth.

Table 2.

Statistics used to estimate chum salmon egg deposition.
Sample sizes are given in brackets.

Brood Year	Percent Females	Number of Females in Population	Mean Female Length mm[a]	Mean Fecundity[b]	Percent Egg Retention
1959	50.7 (3696)	42,335	576 (531)	3050	24.5 (103)
1960	50.0 (3334)	23,746	580 (948)	3100	5.0 (411)
1961	56.2 (3397)	5,857	607 (443)	3400	4.4 (237)
1962	50.4 (10,717)	17,370	582 (531)	3100	5.5 (441)
1963	58.5 (2693)	16,320	589 (913)	3200	2.7 (881)
1964	49.9[c]	12,181	594 (647)	3300	2.8 (647)

[a]Postorbital—hypural plate length.

[b]Estimated from the equation $y = -3400 + 11.23x$, where y = egg content and x = postorbital – hypural length in mm. Egg counts from 164 females taken over a five-year period.

[c]Sex identified on fish passing upstream through the fence.

Table 3.

Statistics used to estimate chinook salmon egg deposition.
Sample sizes are given in brackets.

Brood Year	Percent Female	Number of Females in Population	Mean Length cm[a]	Mean Fecundity[b]
1960	53.0[c] (97)	801	73.1 (51)	4450
1961	36.0[d] (136)	391	66.2 (47)	3800
1962	60.4[c] (207)	475	69.5 (125)	4100
1963	50.0[d] (66)	310	74.4 (88)	4550
1964	30.4[d] (84)	212	69.3 (30)	4100

[a]Postorbital – hypural plate length.

[b]Estimated from the equation $y = -1964 + 87.4x$, where y = egg content and x = postorbital – hypural length in cm. (N = 31).

[c]Sex ratio taken from spawning ground dead recovery.

[d]Sex ratio taken from fish trapped at the fence.

Table 4.

Summary of mark and recapture tests of trapping gear efficiency on juvenile migrant salmon.

Species	Migration Year	Number of Tests	Total Number Released	Total Number Recovered	Percent Recovery	
					Mean	Standard Deviation
Chum	1960	24	23,980	1782	7.4	1.2
	1961	33	33,269	4054	12.2	2.1
	1962	15	15,000	1692	11.3	1.6
	1963	25	24,871	3056	12.3	1.2
	1964	8	7,799	936	12.0	1.5
	1965	9	9,000	1143	12.7	2.6
Coho Smolt	1961	3	1,368	95	6.9[a]	3.0
	1963	8	2,524	525	20.8[b]	7.6
	1964	4	1,711	166	9.7	3.5
	1965	5	1,708	156	9.1	3.2
Late Chinook Fry	1963	2	476	100	21.0[b]	0.5
	1964	6	1,611	121	7.5	3.2
	1965	3	4,008	415	10.4	4.9

[a]The 1961 percent recapture figure was also used to estimate the 1962 smolt emigration and the upper limit of the chinook fry emigration in 1961 and 1962. Similar water velocity situations and arrangements of trapping gear existed at the fence site in both 1961 and 1962.

[b]The stream width at the fence site was reduced during the smolt and late chinook fry emigrations in 1963 to provide higher velocities for trapping and a larger sample of the emigration.

A Downstream Migrant Diversion Screen

by

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Abstract

This paper describes a downstream migrant diversion screen which is located at the intake to the Robertson Creek spawning channel. The structure consists of two parallel concrete flumes, each fitted with an inclined screen. Ninety-eight per cent of the flow passes through the screens and into the spawning channel. The remaining two percent passes over the downstream edge of the screens carrying all downstream migrant fish into a flume which bypasses the spawning channel.

The screens are equipped with electrically-driven screen-cleaning devices which collect and transport algae and trash to a trash bin.

Introduction

The Robertson Creek spawning channel, which was planned and constructed by the Resource Development Branch (formerly the Fish Culture Development Branch) of the Department of Fisheries of Canada, has been described in detail by Lucas (1960) and MacKinnon (1960). Robertson Creek, a secondary outlet from Great Central Lake, joins the main outlet stream, Stamp River, about a mile from the lake. The Stamp then joins with the Sproat to form the Somass River which flows into Alberni Canal at Alberni, British Columbia. Some sockeye and coho salmon yearlings use Robertson Creek as a migration route from Great Central Lake, and in order to prevent these stocks from preying on young salmon fry rearing in the spawning channel, and to prevent adulteration of its experimental stocks a structure was designed to screen the entire flow so as to bypass these migrants around the spawning channel.

The basic concrete structure, which was installed in 1959, is located some 150 feet below the Robertson Creek flow control dam. One side of this double-flume structure was equipped with an experimental type of screen which consisted of panels that could be individually rotated through 180 degrees to allow cleaning by back-flushing (Parkinson, 1959).

This report deals with the permanent screen that replaced the experimental one in March, 1962.

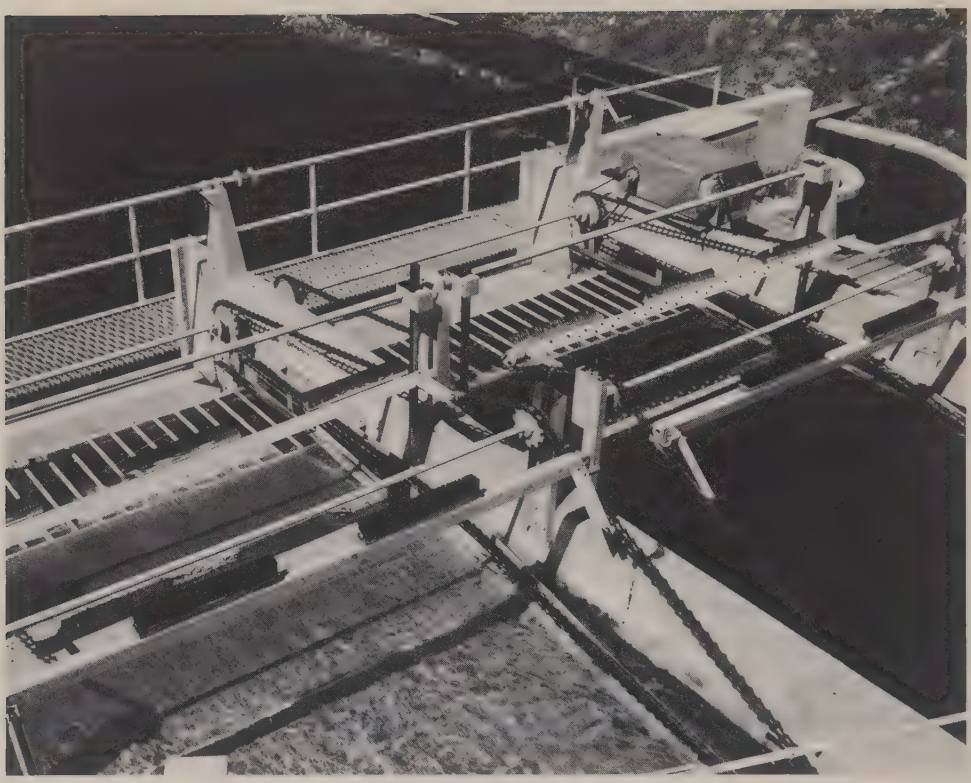


FIGURE 1. *The downstream migrant diversion structure.*

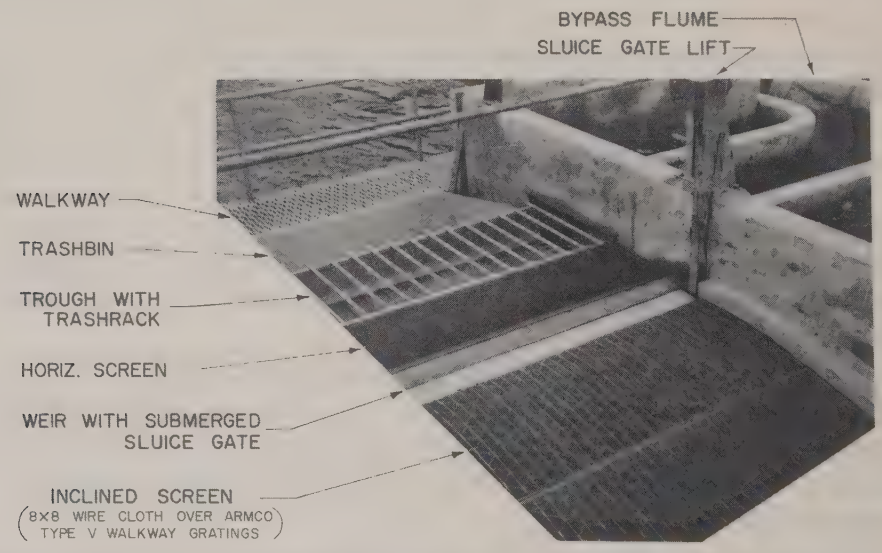


FIGURE 2. *The downstream migrant diversion structure prior to the installation of the screen cleaning device.*

Description of Screen

The Downstream Migrant Diversion Structure consists of two parallel concrete flumes, each with weir and submerged sluice-gate, inclined screens, horizontal screen with shutter assembly, a trough with trash rack, trash bin, and a chain-driven screen-cleaning device.

The inclined screens are each 10 feet wide by 14 feet long. For experimental reasons, different materials were used for the two screens—the right one being made of bronze 8 × 8 square-mesh wire cloth (riddle cloth) with a 0.1-inch opening and an open area of 64 per cent, while the left screen consists of a perforated aluminum sheet 1/16-inch thick, with $\frac{1}{8}$-inch diameter perforations on 3/16-inch centres, with an open area of 42 per cent.

The proposed usage of a self-cleaning device dictated that the screen surface would have to be stretched tight to prevent indentations, and it was found that walkway gratings made an ideal support for the screens. Armco type–V 1¼ × 3/16 aluminum walkway gratings, 33 inches wide by 10 feet long, were used, with the 36–inch-wide screening being stretched tight over the grating and overlapped 1½ inches at the sides, before being riveted to the grating. Five such panels were installed side by side to form one inclined screen. Angle supports fastened to the side-walls of the flume hold the screen panels in position. The spaces between the concrete walls and the outside screen panels are fitted with coverplates to make the installation "fish-tight".

The amount of water entering the collection trough and the bypass system can be controlled by adjusting the sluice-gate settings whenever the discharge into the spawning channel changes. These adjustments are facilitated by a 2-foot wide horizontal screen-and-shutter arrangement which simply requires that the shutter be opened or closed, as required, to increase or decrease the amount of water flowing into the collection trough. This convenient control device could be eliminated, however, if the sluice-gate were equipped with a lift, which was easily operable at the headwater-tailwater differential of two feet.

A collection trough, 3 feet 4 inches wide by 12 inches deep, located downstream of the screen assembly, receives all fish passing over the inclined screen. These fish, together with the flow of 3–5 cfs which spills over the weir crest into the collection trough, are passed around the spawning channel by means of a 30-inch diameter semi-circular wood-stave flume. The collection trough is equipped with crossbars at 6-inch centres which retain debris for removal into the trash bin by the cleaning device.

The screen-cleaning device was installed to remove water-borne debris and algae. It is a double-strand chain conveyor operating on guide tracks and idler sprockets, with provision for adjustment of chain tension by means of a screw take-up. Angle-iron brush-carriers are suspended between the two strands of chain by means of trailing arms which provide for automatic adjustment of the height of the brushes above the screen. This was done to allow for brush wear and to facilitate experiments with different types of brushes of various bristle lengths. As data concerning brushing speed and effectiveness of different brushes were not available, the installation was equipped with the previously-mentioned trailing arm arrangement, and the one-

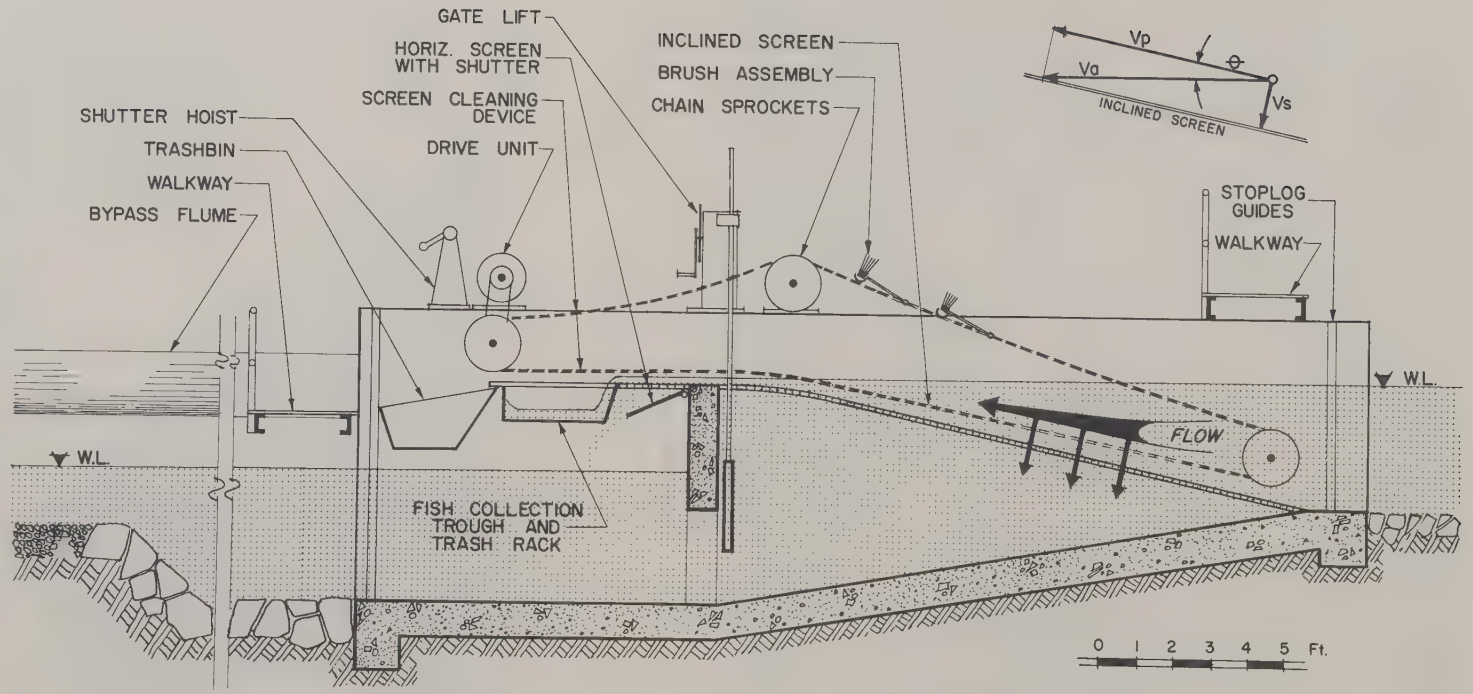


FIGURE 3. *Section of the downstream migrant diversion structure.*

horsepower electric drive unit was coupled with a variable-speed drive having a four-to-one ratio, thereby providing for brushing speeds of from 22 to 88 feet per minute. The brushing speed which most effectively prevents algae build-up on the screen surface was found to be 40–50 feet per minute. The operation of the cleaning device can be controlled manually by means of a starter switch or by electrical timers which automatically regulate the duration of the brushing periods and the operating interval. A limit switch ensures that the brush assemblies will continue to move after automatic shut-off until they are clear of the water.

The screen was designed in accordance with the approach described in detail by Clay (1961). The mean cruising speed of the species of fish to be protected determines the permissible velocity of approach to the screen. The latter can be stated in terms of the minimum area of screening to be provided for each cubic foot per second of flow—the suggested ratios per cfs being 2.5 square feet for travelling screens and 10 square feet for the stationary type.

The installation described herein has the physical characteristics of a fixed screen, but inasmuch as it is equipped with an automatically-controlled screen-cleaning device, its operation is more comparable to a travelling screen. Accordingly, it was designed for an approach velocity of 2.5 square feet of screen per cfs. Observations and experiments have since revealed that, for this type of screen, only 1.5 square feet per cfs is required for the species and conditions encountered at this location (Fig. 4).

Operation

Observations and tests have been undertaken since 1962 to establish operation and maintenance procedures, to note the performance of the installation, and to determine its efficiency for keeping sockeye and coho smolts out of the channel.

After four years of seasonal operation the screen and the cleaning device show no sign of requiring repairs or replacement. A once-daily operation of 4–6 rotations of the cleaning device keeps the screens clean during most of the year but two brushings a day are required during periods of high algae growth or high water levels.

An assessment program was carried out in 1963 to study flow patterns and to observe the manner in which fish passed through the structure.

Flow patterns were determined through the use of dye releases and plastic tapes which were submerged to a depth of 3–9 inches from the screen. At this distance part of the flow is deflected by the screen towards the weir crest, as indicated by the force parallelogram included in Figure 3.

The given force "Va" (approach velocity) can be resolved into two components "Vp" and "Vs", which are, respectively, parallel and perpendicular to the screen. In order to avoid impingement on the screen, fish must overcome the force "Vs". By applying the function $Vs = Va(\sin \Theta)$ we find that with a screen inclination of 12 degrees and an approach velocity of 4.8 fps a fish theoretically has to swim at a speed of 1.0 fps to maintain a constant distance away from the screen.

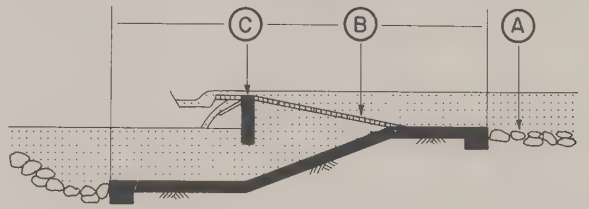
Discharge (cubic feet per second)	Average flow velocity at A Upstream flume-entrance. (feet per second)	Average flow velocity at B 9″ upstream of screen. (feet per second)	Flow velocity on weir crest at C. (feet per second)	"Flow to screen-area ratio". (square feet of screen per each cubic foot of flow per second)	 REMARKS
52	1.5	2.40	2.62	2.88	Safe fish passage observed. (sockeye and coho smolts)
90	2.6	3.55	3.89	1.66	Safe fish passage observed. (sockeye and coho smolts)
150	4.3	5.33	8.48	1	Safe fish passage observed. (sockeye and coho smolts) Strong vibrations in cleaning device, cleaning difficult. Maximum screening capacity of 150 sq. ft. of perforated aluminum screen reached. Flow pattern on horizontal screen should be improved.
210	No velocities were measured.			0.71	Fish passage unsafe over horizontal screen. Cleaning device would not function at these high velocities. Maximum screening capacity of 150 sq. ft. wire mesh screen reached.

Figure 4. *Velocity distribution with varying discharges.*

Observations have shown that fish pass the inclined screen, in the direction of the deflected flow, without darting away or holding in front of it, and that the path they follow appears to be midway between the screen and the water surface. The observations indicate that due to the ideal bypass situation this type of fish screen can operate effectively with approach velocities in excess of those required for conventional-type vertical screens where fish have to maintain their position until they are able to locate the bypass entrance by their own efforts.

Discharge measurements and approach velocities upstream of the screen are shown in Figure 4.

The assessment program included the comparison of the respective merits of the two types of screens which were used. Only one screen was operated at a time and the discharge was increased daily until its maximum capacity was reached. Tests to determine type and degree of injury of fish passing the screen have not been made. However, it is known that smolts did not impinge on the screen. Smolts taken for experimental purposes were held for a number of weeks without mortality, indicating that the screens provided safe passage. This was confirmed by incidental tests undertaken at the Vancouver Technological Station of the Fisheries Research Board of Canada. In two successive years sockeye smolts removed from the bypass flume downstream of the diversion screen were transported to the Vancouver Station and held without mortality for a considerable period of time. Prior to the experiments they were found to be in good to excellent condition.

Although the Robertson Creek screen operated at discharges of up to 150 cfs per screen, a safety factor is advisable and it is recommended that 150 square feet of wire mesh screen be provided for each 100 cubic feet per second of flow. Approach velocities in the range of 2–4 feet per second, with up to 5 fps at the bypass entrance (weir crest), can be regarded as safe for the species studied to date.

Brett and Alderdice (1958) recommend a uniformly-accelerating velocity of flow (not greater than 0.1 feet per second per foot of length) with a final velocity of 5 fps at the bypass entrance, as an ideal condition for guiding sockeye and coho salmon smolts into a bypass system. The Robertson Creek screen installation approximates this criterion when the discharge is 100 cfs per flume.

In comparison with other types of screens capital costs of the Robertson Creek installation are low because of the small area-discharge ratio and the higher permissible velocities of approach. Assuming a screen capacity of 200 cfs the unit price per cubic foot of flow per second is $145, based on the 1961–62 construction prices, and exclusive of the costs of the bypass flume and cofferdamming.

Clay (1961) describes a number of screens for which he suggests the following capital costs:

Revolving Drum screen	$150 per cfs
Stationary screens	$150–$1,000 per cfs
Travelling screens	$1,000 per cfs
Louvers	$300–$400 per cfs

Conclusion

In its four years of seasonal operation the downstream migrant diversion structure has clearly indicated that it combines the advantages of stationary screens with the convenience of self-cleaning travelling screens. Its advantages are: low capital and maintenance costs, high efficiency, simplicity of design and the ease with which fish locate the bypass. Its disadvantages are: a two-foot head loss and the frequency with which it requires adjustments to compensate for varying discharges.

While both test screens performed well, the 8-mesh wire screen is regarded as preferable to the perforated aluminum screen because: it is less expensive, easier to install, has more open area, and is less likely to become clogged with algae and pea gravel.

The downstream migrant diversion screen, as described, appears to be a practical fish screen for water intakes of from 50–1,000 cfs.

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A Field Assessment of the Effects of Spraying a Small Coastal Coho Salmon Stream with Phosphamidon

by

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and

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Introduction

Aerial forest spraying methods utiiizing DDT formulations have been employed for many years for control of forest insect pests in British Columbia. Since many forest insect control programs must be carried out during summer months when water temperatures are high and stream flows are often critically low, salmonid fishes inhabiting streams within such areas are particularly susceptible to the effect of most pesticides. In recognition of this hazard, certain measures such as the reduction of dosage to ¼ from ½ lb DDT per acre and the provision of buffer swaths on each side of streams within areas affected, have been adopted to minimize the danger of killing fish, and aquatic insects. Buffer swaths, which prevent direct entry of DDT into streams requiring protection, have been successfully used in the past, but they often leave dense and commercially valuable stands of timber in the river valleys susceptible to heavy defoliation and incipient heavy mortality. It has been recognized that it would be desirable to apply insecticides other than DDT which would achieve control of defoliating forest insects, but at the same time not endanger indigenous fish populations. For this reason it was considered desirable to employ some other insecticide in the critical buffer swath areas in British Columbia. Tests carried out by the Chemical Control Section of the Department of Forestry indicated that the systemic organo-phosphate insecticide Phosphamidon showed promise as a means of control of spruce budworm larvae in New Brunswick and bio-assays carried out by the Fisheries Research Board of Canada indicated that salmonid fishes could probably tolerate much higher dosages of this insecticide than would normally be required to control insects. Because of the indicated difference in tolerance between salmonids and budworm larvae, a co-operative program was planned in which the Department of Forestry and the Department of Fisheries carried out experiments to ascertain the degree of control which could be obtained with Phosphamidon on hemlock looper larvae at 1 lb active ingredient per acre and the effect on juvenile coho salmon inhabiting a small stream which might typically be found in a treatment area. Moran Creek, a tributary of the Ash River near Port Alberni was selected as the experimental

site. The location of Moran Creek is shown in Figure 1. In July, 1963, the indigenous juvenile coho salmon population in Moran Creek was very high, the flow was extremely low and the water temperature was high. Cover consisting of second growth Douglas fir and alder between twenty and thirty feet high was typically dense along the banks of the stream, but little of the stream bed was obscured by this cover, so that it was deemed feasible for a helicopter to follow the stream bed and deposit the highest possible dosage of insecticide directly into the stream. It was considered that this combination of adverse physical conditions simulated the greatest danger to fish which could be encountered in treating coastal areas traversed by salmon streams.

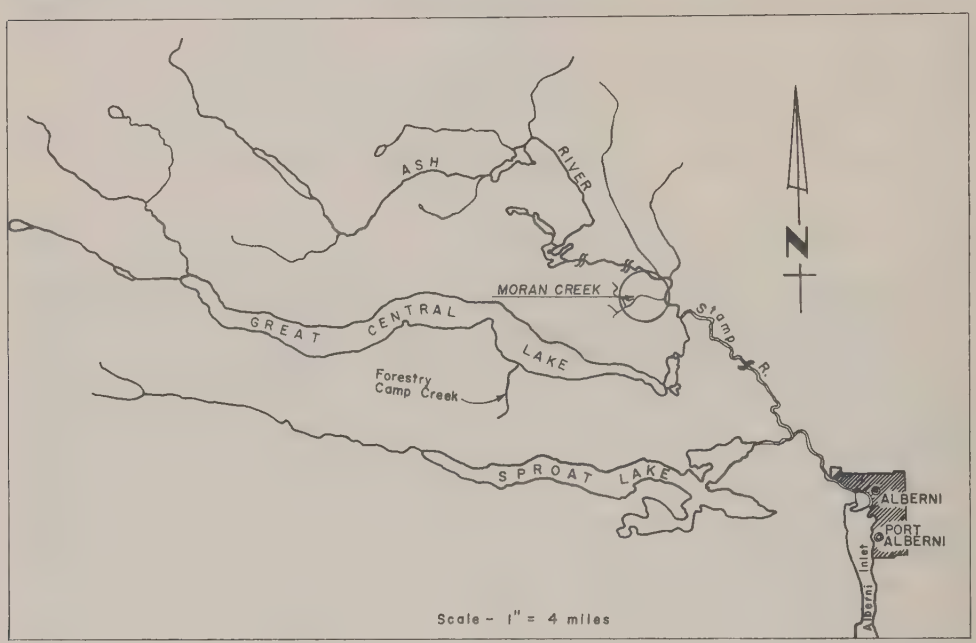

FIGURE 1. *Location map, Moran Creek.*

Methods

Forty-three hundred feet of Moran Creek was treated by helicopter with a 25 percent water solution of Phosphamidon to yield an average dosage of 1 pound active ingredient per acre. This mixture was applied in a single swath in a downstream direction, directly over the stream.

Four stations were established, a control station located 100 yards upstream of the spray area, and three stations were located within the spray area at the following positions:

(1) Station 1 located 1,200 feet downstream from the upper spray boundary.

(2) Station 2 located 2,900 feet downstream from the upper spray boundary.

(3) Station 3 located 4,300 feet downstream from the upper spray boundary.

The position of these stations is shown in Figure 2. They were established in quiet pools having a depth of at least 18 inches. Liveboxes and aquaria were placed at each station, including the control station, as follows:

(1) A 2′ × 2′ × 3′ uncovered wire mesh livebox containing 50 coho salmon fry.

(2) A 12″ × 12″ × 18″ submerged cage of perforated metal containing 30 coho salmon fry.

(3) An aquarium containing 3 Imperial gallons of water (unaerated) and 30 coho salmon fry. The aquaria were immersed in the stream so that the contents would assume the same temperature as the stream. No lids were placed on the aquaria which could have prevented the arrival of insecticide in the aquaria.

(4) A 6″ × 12″ × 12″ submerged cage of perforated metal containing 20 caddis larvae.

(5) An aquarium containing 3 Imperial gallons of water (unaerated) and 20 caddis larvae. These aquaria were also immersed in the stream and had no lids.

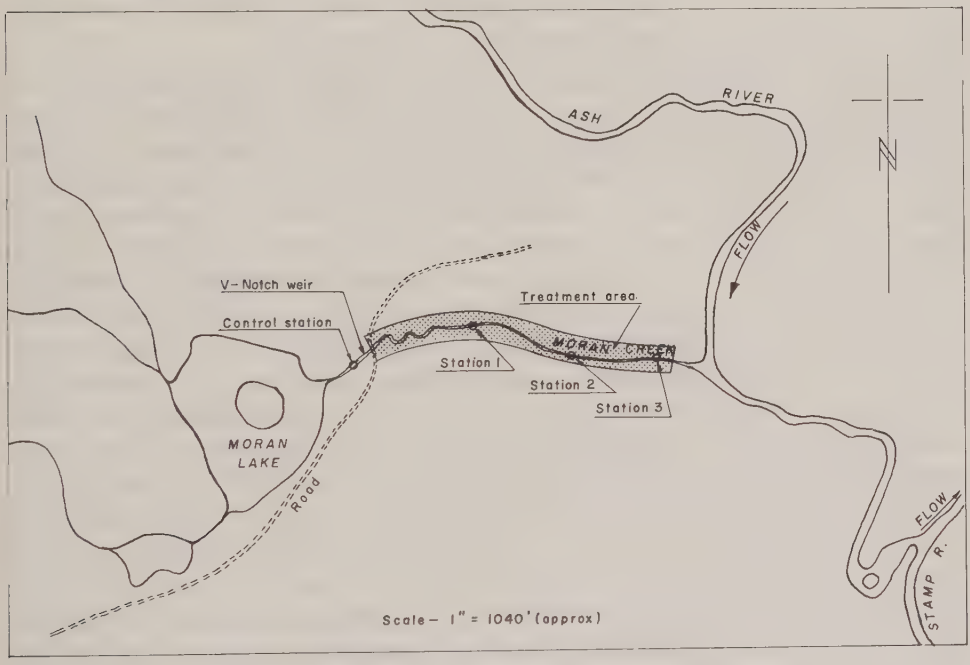

FIGURE 2. *Moran Creek showing experimental stations and treatment area.*

Coho salmon fry and caddis larvae were obtained in the immediate vicinity of each station.

To determine the approximate period of exposure to high concentrations of the insecticide, a charge of Rhodamine B dye was released in Moran Creek at the upstream spray boundary and the time required for the dye first to appear at each of the experimental stations was recorded.

Prior to spraying, the wetted area of the creek was determined by measuring successive increments of length and estimating widths corresponding with each increment. In addition, markers were erected at 100-foot intervals to facilitate the recognition of sub-areas and to serve as locations for spray deposit assessment.

A 2″ × 12″ plank, cut to conform approximately to the bottom contour was laid across the stream and a sheet of polyethylene was attached to the top of the plank and gravel was shovelled over the sheet to form a low watertight dam. A short staff gauge was installed in the pool formed by the dam and a 90° inverted V-notch was cut into the plank. By using the formula $Q = 2.52\ H^{2.47}$, it was possible to calculate the discharge (Q) of Moran Creek, the height (H) being the difference in elevation between the apex of the notch and the surface of the pool.

Before spraying, sufficient methylene blue was added to the spray mixture to give a 0.5 percent dye solution by weight. Window-panes measuring 10″ × 12″ were cleaned, dried and laid horizontally on the ground at the ends of 300-foot sections within the spray area and at each livebox station including the control station. The glass plates were set out to enable an assessment of dye concentration and spray deposition to be made. Within an hour after spraying all glass plates were collected, numbered and stored in a wooden box, the sides of which were slotted to admit the plates. The box was fitted with a lid to exclude light.

In the laboratory before extracting the Phosphamidon-dye mixture with water from the glass plates, some preliminary work was carried out to determine the wavelength at which methylene blue produced maximum light absorbance. A Bausch and Lomb Spectronic 20 colorimeter was used for this purpose. For a freshly prepared 0.5% methylene blue-Phosphamidon solution, the wavelength producing maximum absorbance was 660 mu. A series of dilutions was made and the percent absorbance produced by each was plotted against concentration to yield a calibration curve. A sample of methylene blue-Phosphamidon mixture saved from the field experiment was diluted and the concentration of methylene blue computed from the dilution ratio agreed well with the concentration as measured by the colorimeter, indicating that the methylene blue in the spray mixture had remained stable over a period of 2½ months. The glass plates bearing the methylene blue-Phosphamidon mixture were clamped at an inclination of about 30 degrees over a glass tray the same width as the plates. Dye and insecticide were removed from the plates by applying a fine spray of water and by wiping off the droplets deposited on the plates with a windshield wiper. Each plate was sprayed and wiped at least five times. Further spraying was found to produce an absolutely colorless solution visually. This technique made it possible to recover all of the dye-insecticide mixture from the glass plates in a volume of less than 100 mls. The volume recovered was made up to 100 mls and the percentage absorbance determined by using the colorimeter. From the corresponding concentration of dye on the calibration curve, and the ratio of dye to insecticide in the spray mixture it was possible to calculate the amount of Phosphamidon deposited per unit of area at each station and within each 100-yard section of stream. The total volume of water in the stream in the treated area was calculated by multiplying the stream discharge by the time taken for the Rhodamine B dye to pass through the treated area. Since the wetted area of the stream also had

been measured, it was possible to calculate the mean depth of the stream, and to obtain an estimate of the initial insecticide concentration in the stream and at the experimental stations.

To obtain an indication of the concentration of Phosphamidon and the duration of exposure required to produce a kill, a bio-assay was conducted "in situ" at a point 50 feet upstream of the sprayed area. Uncontaminated dilution water from the creek was used and the aquaria were submerged in the stream to hold their contents at stream temperatures. A preliminary screening involving the exposure of juvenile salmon to a broad series of concentrations of Phosphamidon arranged in multiples of ten, indicated that no mortality would take place at concentrations below 1 ppm after 24 hours exposure, and a complete kill would take place at concentrations of 10 ppm or more. This concentration range was broken into equal intervals on a logarithmic scale of 10, 5.6, 3.2, 1.8 and 1.0 ppm, and 25 coho salmon fry were exposed for periods of 24 and 48 hours to each concentration, in a volume of 7.5 litres. To avoid dissolved oxygen depletion air was bubbled through an air-stone in each aquarium supplied by a compressed air cylinder fitted with a pressure reducing valve.

Results

Mortalities of captive coho salmon fry and caddis larvae resulting from exposure to Phosphamidon are shown in Table I. One fish died in the control cage, two died in the aquarium at Station 2 and one died in the open livebox at Station 3. Such minor mortalities are not uncommon during field tests and could have been attributable to injuries sustained in trapping and transfer to the liveboxes rather than to the effects of Phosphamidon. The complete mortality of caddis larvae in the cages and aquaria at all but the control station and Station 3 showed that they had received a lethal dosage of Phosphamidon. (Station 3 was not sprayed, so that no insecticide arrived in the aquarium. The mortality of caddis larvae in the cage must have been due to the arrival of contaminated water from the area treated upstream).

A record of daily observations of mortality and behavior of non-captive coho salmon fry and caddis larvae in the treated area of Moran Creek is presented in Table II. The fact that these coho fry were observed to be active and feeding suggests that they were not impaired by the dosage of Phosphamidon delivered into the stream. The early incidence of moribundity and death of caddis larvae substantiates the results presented in Table I.

Rhodamine B dye was released at the upstream boundary of the area to be treated on June 27. The first sign of red coloration appeared at Station 1 after 2 hours and 5 minutes had elapsed, after 8 hours and 15 minutes at Station 2 and after 27 hours and 5 minutes at Station 3.

Table III shows the area of each section of Moran Creek which was treated. A total wetted area of 32,392 square feet was sprayed. Unfortunately the supply of Phosphamidon was exhausted at a point 1200 feet above the lower boundary of the experimental area. The experimental area actually occupied 42,230 square feet. The time required for the Rhodamine B dye to pass through the whole experimental area was 27 hours and 5 minutes, and by multiplying this time by the discharge, the volume of water in the experimental area was calculated to be 23,302.5 cubic feet.

By dividing this volume by 42,230, the mean depth of water in the experimental area was found to be 0.55 feet. An estimated 692.90 grams of Phosphamidon was deposited over the treated part of the experimental area, and further calculation showed that the averge concentration of Phosphamidon in this area was 1.37 ppm. Coho salmon fry and caddis larvae held at Station 3 were not directly sprayed, but were exposed to Phosphamidon because they were located below the treated area. It was considered that these specimens must have been exposed to concentrations initially lying between 1.37 ppm and at least $1.37 \frac{(32,392)}{(42,230)} = 1.05$ ppm, while those at Stations 1 and 2 were considered to have been exposed to concentrations of 1.37 ppm initially. No Phosphamidon was deposited on the Control station.

Stream temperatures during the period of July 1 to July 6 are shown in Table IV. A sample of water taken from the stream on July 4 was found to have a dissolved oxygen concentration of 9.4 ppm. The average fork length of 31 coho salmon fry of the same stock used in the tests was 55.5 mm, ranging from 42 mm to 63 mm.

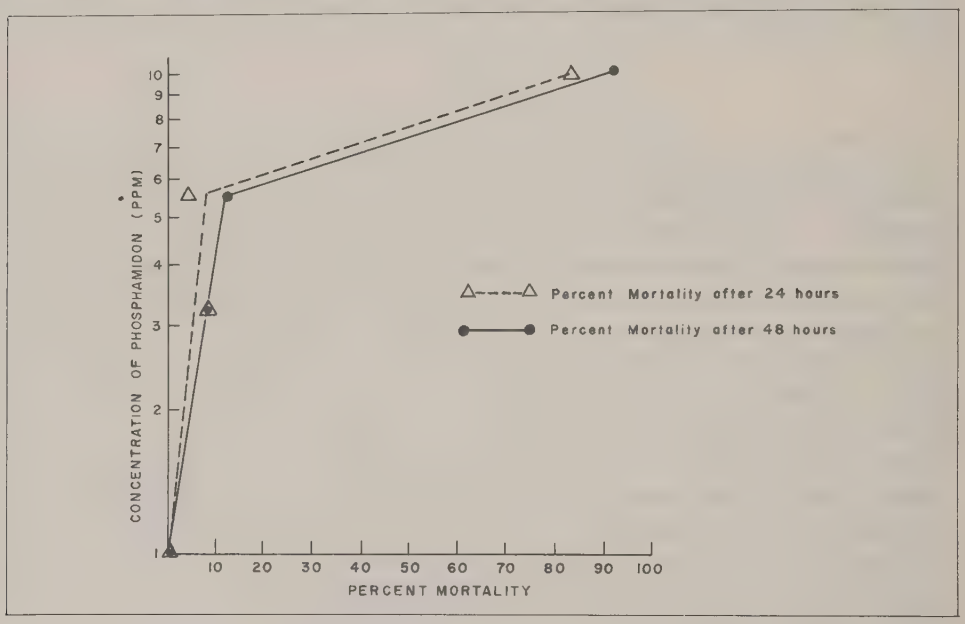

FIGURE 3. *Results of exposing juvenile coho salmon to Phosphamidon.*

The results of the bio-assay presented in Figure 3 show percentage mortalities plotted against common logarithms of Phosphamidon concentrations.

Discussion and Conclusions

The bio-assay data seem to indicate that concentrations of Phosphamidon between 1.0 and 3.2 ppm would cause a light mortality of juvenile coho salmon in a period of 24 hours. The almost complete survival of caged and indigenous fish in Moran Creek shows that they were not exposed to lethal dosages. However, the calculated initial average concentration of 1.37 ppm fell within the limits found to

cause a light mortality during 24 hours of exposure. While it is acknowledged that the concentration must have declined from 1.37 ppm due to displacement and dilution of the insecticide, it is considered that the dosage of Phosphamidon which arrived in the creek was probably close to a level which could have produced a light mortality. Had the spraying been part of a program involving the treatment of a large area traversed by several small and sparsely covered coho streams, it would have been appropriate to have avoided them or to have reduced the rate of application of insecticide in their vicinity. On the other hand, had the area been traversed by a large swiftly flowing river, the hazard to fish would probably have been negligible.

It might now be appropriate to mention that a lethal dosage of a toxin is regarded to be a function of the product of concentration and exposure time. Hence not only the concentration of insecticide arriving in the stream is important but the "flushing" rate of the stream and the position of fish in the stream relative to the upstream boundary of spraying are also important. The progressive increase in times for arrival of dye at the three stations quite amply illustrates the fact that exposure time can be greatly prolonged with increasing distance from the upstream boundary of spraying in a poorly flushed stream. The times for arrival of dye indicate also that the longer the section of stream sprayed the greater the likelihood of a lethal dosage prevailing. It would probably be informative to release dye into selected small slow-flowing streams prior to conducting a major spray program to obtain an assessment of exposure time in each stream.

The apparent lethality of Phosphamidon to caddis larvae is unfortunate but it must be pointed out that the compound which it could replace, DDT, has also been reported to have been lethal to aquatic insects at very low rates of application. In spite of this shortcoming it is considered that the use of Phosphamidon at 1 pound per acre would be greatly preferable to DDT in the vicinity of waters inhabited by fish. At this rate of application it is unlikely that dosages toxic to fish would arrive in all but the smallest and most exposed streams, for which previously mentioned precautions could be taken. While Phosphamidon spraying could diminish their food supply, the diet of coho salmon fry consists of both aquatic and terrestrial insects, not precluding the possibility that sufficient food might be available until aquatic insects became re-established. When Moran Creek was inspected on August 15, 1963, the population of coho salmon fry appeared to be substantial and these fish were seen feeding actively on insects alighting at the water surface.

It has been impossible in the past without recourse to chemical analysis to equate the application rate of an insecticide, which is always expressed in pounds per acre, with the concentration of insecticide arriving in the stream and the duration of exposure of fish in the stream. The techniques which have been described are so time-consuming that they would not be practical for estimating initial insecticide concentrations in many streams in the course of forest insect control programs. However, they did enable the necessary comparison to be made between insecticide concentration and exposure time under field conditions with the same combination of variables controlled under bio-assay conditions. Also, by deliberately spraying a small, highly vulnerable stream it was possible to obtain a useful forecast of the effects of applying an insecticide at a dosage which was known beforehand to be adequate to control a forest insect pest infestation.

Table I

Numbers of Coho Salmon Fry and Caddis Larvae Dead after Spraying with Phosphamidon.

	Number dead											
Time elapsed (hrs : mins)	5:20		24:10				77:00		105:50	127:35	145:00	Control Station
Coho aquarium	0		0				0		0	0	0	
Coho cage	0		0				0		0	0	1	
Coho open livebox	0		0				0		0	0	0	
Caddis aquarium	0		0				0		0	0	0	
Caddis cage	0		0				0		0	0	0	
Time elapsed (hrs : mins)	4:40	11:50	23:10	30:36	47:40	52:08	71:35	82:50	102:50	127:00	145:00	Station 1
Coho aquarium	0	0	0	0	0	0	0	0	0	0	0	
Coho cage	0	0	0	0	0	0	0	0	0	0	0	
Coho open livebox	0	0	0	0	0	0	0	0	0	0	0	
Caddis aquarium	0	20	20	20	20	20	20	20	20	20	20	
Caddis cage	10	20	20	20	20	20	20	20	20	20	20	
Time elapsed (hrs : mins)	3:58	11:20	23:30	30:43	47:25	52:14	71:20	82:50	102:20	127:00	145:00	Station 2
Coho aquarium	0	0	0	0	0	0	1	1	1	2	2	
Coho cage	0	0	0	0	0	0	0	0	0	0	0	
Coho open livebox	0	0	0	0	0	0	0	0	0	0	0	
Caddis aquarium	0	16	20	20	20	20	20	20	20	20	20	
Caddis cage	0	20	20	20	20	20	20	20	20	20	20	
Time elapsed (hrs : mins)	3:35	11:20	23:45	30:50	47:15	52:15	71:15	76:50	102:30	127:00	145:00	Station 3
Coho aquarium	0	0	0	0	0	0	0	0	0	0	0	
Coho cage	0	0	0	0	0	0	0	0	0	0	0	
Coho open livebox	0	0	0	0	0	0	0	0	0	1	1	
Caddis aquarium	0	0	0	0	0	0	0	0	0	0	0	
Caddis cage	0	0	19	20	20	20	20	20	20	20	20	

Table II

Daily Observations of Behaviour and Mortality of Coho Salmon Fry and Caddis Larvae in Moran Creek Following Spraying with Phosphamidon

Date	Coho Salmon Fry			Caddis Larvae
July 1 am	active	feeding	no mortality	present alive
July 1 pm	active	feeding	no mortality	present moribund
July 2	active	feeding	no mortality	present all dead
July 3, 4, 5, 6, 7, 8	active	feeding	no mortality	present all dead
August 15	active	feeding	no mortality	none present

Table III

Areas of Sections of Moran Creek, and Calculated Weights of Phosphamidon Deposited in Each Section

Section	Area of Each Section in Square Feet	Grams of Phosphamidon per Square Foot Each Section	Grams of Phosphamidon Deposited in Each Section
1200′—1400′	1,532	0.183349	28.0890668
1400′—1500′	802	0.0160431	12.8665662
1500′—1800′	3,281	0.0275024	90.2353744
1800′—2100′	3,157	0.03323215	104.9138975
2100′—2400′	3,735	0.00916749	34.2405751
2400′—2700′	2,828	0.0068756	19.4441968
2700′—3000′	2,924	0.0515671	150.7822004
3000′—3200′	1,745	0.0160431	27.9952095
3200′—3600′	4,057	0.0252106	102.2794042
3600′—3900′	3,920	0.0194809	76.3651280
3900′—4200′	2,681	0.0126053	33.7948093
4200′—4300′	1,730	0.0068756	11.8947880

Total Area Sprayed = 32,392 sq. ft. Total weight Phosphamidon = 692.9012163 gms.

Table IV

Temperature of Moran Creek Over the Period July 1 to July 6, 1963

July 1 (p.m.)	64°F.
July 3 (p.m.)	69°F.
July 4 (p.m.)	66°F.
July 6 (p.m.)	65°F.

The role of the Department of Fisheries of Canada in dealing with problems presented by the use of pesticides in British Columbia.*

by

K. J. Jackson

Department of Fisheries of Canada.

The purpose of this paper is to discuss the policy and approach which the Department of Fisheries of Canada has adopted toward the use of pesticides in British Columbia, but before discussing these matters it would be appropriate to discuss the sources of the problems which have made it necessary to develop a policy.

One finds insecticides used on a large scale in forest insect control in British Columbia, and to a lesser extent in mosquito control and agriculture. Herbicides such as the common 2,4-D and 2,4,5-T and more recently salts and esters of trichlorophenoxypropionic acid are used on quite a large scale in forestry as a means of accelerating the succession of valuable coniferous species, and they are also used as brush control agents along highways, power line, railroad and telephone line rights-of-way. Sodium arsenite is used on quite a large scale to kill marine borers infesting floats, wharves, drydocks and sawlogs held in salt water storage areas, and copper sulfate is used to control snails responsible for the transmission of swimmer's itch in some of our lakes which are popular for swimming.

The insecticides and herbicides are often applied by fixed-wing aircraft or helicopters over very large areas in the dimensions of hundreds of thousands of acres. Our Department is fully aware of the hazards to commercially and recreationally valuable species of fish which accompany the use of pesticides. The literature is filled to repletion with citations of toxicity tests and descriptions of fish kills which show that many modern pesticides, particularly insecticides, are unquestionably deleterious to fish, which is not at all surprising when one considers that these compounds have been consciously selected so that a minute quantity will disrupt a key physiological process. Unfortunately such processes are common to all animals, so that most insecticides will kill or injure species other than the pest which one sets out to control. This is the dilemma which is at the root of problems associated with pesticide applications today.

The Federal Fisheries Act broadly prohibits the discharge of substances which are deleterious into waters inhabited by fish, and while pesticides are not specifically

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named as deleterious, they are so regarded, and the Act directs the Department to prevent their discharge and to penalize persons responsible for killing fish. This presents another dilemma.

Clearly the simplest way for the Department to discharge its responsibility would be to prohibit the use of all poisonous pesticides over or near waters inhabited by fish. Whether this position would be tenable is debatable. To maintain it, would be to totally disregard the need of other resource-users to protect their forests or crops, and of course to be thoroughly consistent one would have to ban the use of insecticides for the protection of public health.

Fisheries Department Policy

Our Department has not adopted this course because we consider such a policy would not serve the best interests of the country. Instead, our Department's policy has been to recognize that some people must take advantage of the benefits conferred by pesticides, but we have also adopted the position that if toxic chemicals must be used, that they must be applied with our knowledge, and then with precautions to minimize the accompanying hazards to fish. Furthermore, it is considered that our Department has a place in the planning of programs affecting its interests.

With these views in mind, we have approached the major sponsors of programs and applicators of pesticides in British Columbia. This has led to participation in the planning of their programs from the earliest stages to the final stage of field application. This approach has been successful and profitable to our Department, to the applicators, and most important to the plurality of resources requiring protection.

The Department has taken a very active interest in pesticides since 1957, following an extremely heavy fish kill caused by the application of DDT over Northern Vancouver Island. Since that time there have been many spray programs in British Columbia. In 1965, for example, there were fifteen insecticide applications, twelve herbicide applications, several applications of sodium arsenite, and two copper sulfate applications for the control of swimmer's itch. These in all cases were carried out with the Department's sanction and were subject to appropriate precautionary measures. A similar number of programs was conducted in 1964, and previous years, and there have been no fish kills associated with such co-operatively planned programs since 1957.

It would not be correct to say there have been no kills at all. There certainly have been; notably the incident at Shuswap Lake in 1963 when three million juvenile sockeye and spring salmon were killed following the application of DDT for the control of adult mosquitoes, and there was another incident which coincided with the dumping of garbage containing two half-filled cartons of flea powder into the Campbell River, a small but productive coho and trout stream in the Fraser Valley. These kills took place however in instances where our Department's advice was not solicited.

While we would be very reluctant to prescribe the co-operatively planned program as a "recipe" for complete safety, we do consider it gives the best protection today, and it will probably remain a practicable approach until highly specific chemicals, and a repertoire of successful methods of biological control become available. So much for our Department's policy and the reasons for it.

Co-operative Planning

The development and maintenance of suitable mechanics for co-operative planning requires watchfulness and work. Our Department's Fishery Officers in the outlying districts have been alerted to the dangers associated with the use of pesticides and are required to report any plans developing in their areas and to direct the people involved to acquaint our Vancouver headquarters with their plans. The Officers have specially prepared data sheets which they provide to prospective pesticide users and on these sheets there are questions intended to elicit information on the area, the chemical, the dosage, the timing of application and method of application.

Because pesticide applications are seasonal and very often repetitive, the Fishery Officers soon learn who is applying pesticides in their areas. This kind of liaison serves well to allow our Department to assess and recommend precautions for smaller programs, for example mosquito sprayings, which might otherwise pass unnoticed until followed by a fish kill. The remaining liaison is conducted at the "company" level from Vancouver headquarters.

The major logging companies in British Columbia through their B.C. Loggers' Association have formed a Pest Control Committee which meets at frequent intervals to discuss the results of surveys of forest insect pest infestations, which for the most part are carried out by the Department of Forestry of Canada. The Department of Fisheries is a member of this committee and members of its technical staff attend meetings. In this way they maintain an awareness of current problems, and are available to offer advice on the presence or absence of fish in areas which may be sprayed and to suggest steps which should be taken to avoid applying sufficient insecticide to kill fish.

For example, spraying of floating log booms with benzenehexachloride has taken place annually at four locations on Vancouver Island for the past six years. A typical site is Cowichan Lake. Ambrosia beetle flight takes place usually from mid-April through to June, and if a protective deposit of BHC is not placed on the exposed surfaces of the logs, the female ambrosia beetle will alight, seek crevices in the bark, burrow into the woody parts of susceptible logs and lay her eggs in the tunnel which she has created. High grade sawlogs to be used for lumber or peeler logs can be riddled with "pinholes" which render them unfit for their intended use and furthermore infested lumber or logs are unfit for export to certain countries which are rightfully concerned about the possibility of introducing new species of insect pests.

Benzenehexachloride was selected because it is a stable insecticide which, if applied early, can afford protection through the season of attack, but it is also a compound which is very toxic to fish, and many of the log storage sites are located in areas where fish could certainly be killed. It has been necessary for our Department to request at Cowichan Lake that logs be sprayed prior to April 15 which precedes the displacement and emigration of newly emerged coho fry from streams tributary to the lake. It has been concluded from repeated examination that no coho fry will be found taking cover under the log booms by April 15, although they have been seen swimming within the booms as early as April 20–25.

Because we must operate within such a close margin of time, particularly if the preceding winter has been mild, the tributary streams are visited a week and two weeks

prior to spraying to establish whether the emergence of fry has taken place. In addition to attempting to precede the arrival of coho fry of the year in the lake, it is necessary to prevent the spraying of logs in areas near the outlets of lakes or logs held in tidal estuaries because large numbers of salmon smolts must pass through these areas in the spring in the course of their seaward migration. Logs are towed from these sites to points where high densities of fish are not expected to be found.

As a matter of necessary routine a Fishery Officer is present and examines booms for presence or absence of salmonid fishes prior to spraying with the understanding that spraying will be deferred if fish are present, but to date no postponements have been needed. As a matter of common sense, we have prescribed that all personnel handling spray materials be told that the preparation of chemicals and the cleansing of spray equipment must take place in areas well removed from waters inhabited by fish and that any surplus spray materials must be buried in containers.

Necessity to Spray

Where large areas of forest land traversed by small streams or rivers are threatened by defoliating insects, the question of whether spraying is necessary is seriously examined. If in the judgment of experienced entomologists, the results of surveys of existing defoliation coupled with the results of surveys to determine egg, larval, or pupal densities indicate that one more year of heavy defoliation is incipient and likely to cause a substantial kill of trees, preparations are made to conduct a control program. The usual outcome of this approach is to limit the area requiring treatment to only a part of the total area infested.

The eradication of a pest species by chemical means is of course regarded to be an impossibility, and the piecemeal treatment of huge areas of forest which are infested but capable of surviving another year of attack is regarded to be unnecessary and premature because the chances are usually in favour of a population decline brought about by factors of attrition such as parasitism, disease, heavy predation or a heavy overwintering mortality.

When treatment becomes a certainty, and the area needing treatment has been defined, records of adult salmon escapement to all streams within the area are carefully examined with a view to obtaining as much information as possible on the probable presence and distribution of species such as coho and sockeye salmon as opposed to pink and chum salmon which usually have migrated seaward by late spring or summer during which time the program usually takes place.

A field reconnaissance of the area is made in order to confirm presence or absence of susceptible species of fish, and during the reconnaissance the configuration of each stream, the amount of protective forest cover and the presence of natural landmarks which would enable smaller streams to be identified by moving spray aircraft are noted. With these factors in mind an assessment of hazard is made and if extremely toxic spray materials such as DDT are to be used, as is usually the case, it is prescribed that the applicators leave buffer swaths untreated along the margins of rivers and streams known to be inhabited by fish. It is further prescribed that spraying be conducted at a time when wind drift will carry the insecticide away from rather than toward the stream.

In addition to these precautions a firm attitude is taken against the use of more than the minimum amount of chemical needed to achieve control of the pest. Before a large program starts; a section of a stream will be sprayed at this minimum dosage and from holding caged fish in the stream it can be ascertained whether the minimum dosage is likely to cause a kill. During a spraying operation on Moresby Island in 1960, involving an area of some 31,500 acres, a minimum dosage of ¼ lb DDT per acre failed to produce mortality in a small coho stream when it was directly sprayed on the stream. Thus we considered that the buffer swaths, which were ½ mile wide, would afford the needed protection and this judgment was vindicated by the absence of a kill following spraying in the entire area treated.

Substitutes for DDT

More recently our Department has moved into the area of co-operatively assessing the toxicity and comparative hazard presented by chemicals which might be used as substitutes for the highly toxic DDT which is still favoured as the control agent in large spray programs. We have participated in the field testing of insecticides such as *Bacillus thuringiensis*, Phosphamidon and Dimethoate. Such tests involve the placement of juvenile salmon and aquatic insects in cages and static aquaria in a small stream which is then deliberately sprayed with the insecticide at a dosage previously judged from the results of laboratory studies to be adequate to control the pest.

Very small streams are deliberately chosen because in them the dilution factor is least and produces the highest hazard. From the absence or incidence and degree of mortality of fish and of aquatic organisms which form part of their food supply, it may be ascertained whether the hazard will be substantial or small at the selected dosage rate.

Bio-assays are conducted concurrently in the field to determine the concentrations which would be acutely toxic to fish and these concentrations are compared with those actually found in the treated area. Dyes are released in the test stream to obtain an indication of the duration of exposure.

One difficulty which has been overcome in these field tests is related to the general practice of expressing dosage in terms of pounds of insecticide per acre which is not reconcilable with the concentration factor which partly determines survival and is, of course, an expression of weight of insecticide per unit of volume.

Our Department has developed two methods of measuring insecticide concentration. Briefly, the first involved obtaining a measure of volume of the stream and then of finding means of assessing the insecticide dosage in terms of weight deposited per unit of surface area from which the concentration may be computed. The weight of insecticide deposited per-unit of area was determined in the first experiment by adding methylene blue dye in a fixed ratio by weight to the insecticide before spraying. Glass plates were laid flat on boulders or supports in the stream and after spraying the dye was washed off the plates with a fine water spray. By using a spectrophotometer the amount of dye and hence the amount of insecticide on each plate was determined, and from this data the average deposition over the entire stream was calculated.

In 1965, using Rhodamine B500, which is a fluorescent dye which can be detected at levels of one part in a hundred billion parts of water, it was possible by using a fluorometer to trace the change in concentration and duration of exposure in a small stream sprayed with Dimethoate. Both the technique and the insecticide appear to be very promising, and further tests will be conducted. Chemical analyses of water from the stream are lengthy and so expensive that it is rather difficult to envisage the possibility of routinely conducting statistically reliable sampling programs in connection with large scale spraying operations. It may be that Rhodamine as a tracer will afford means for assessing concentration during future programs.

Phosphamidon and Dimethoate are relatively new insecticides and both possess a higher degree of specificity than the DDT which they are intended to replace in British Columbia. Baytex, another relatively new insecticide, was used on quite a large scale with success as a mosquito larvicide in breeding pools adjacent to waters inhabited by fish. These are the insecticides of the immediate future and are much better than the old broad spectrum insecticides. They are costly and their application may take more knowledge. Their arrival is timely. They should be accepted and regarded as steps along the path toward the development of highly specific pecticides and methods of biological control which will enable all our natural resources to be protected and utilized to the full.